Chemical Science Review and Letters ISSN 2278-6783

www.chesci.com Research Article

Calibration and Optimization of Economical Portable Devices for Copper and Nickel Analysis in Aquaculture Systems

Kesavan Devarayan,[1,*] Kaviyasri Elango,[2] Anand Theivasigamani,[3] Deepika Ananda Kumar Muthurani[1], Geetha Kannusamy[1]
[1]Department of Basic Sciences, College of Fisheries Engineering,
Tamil Nadu Dr.J.Jayalalithaa Fisheries University, Nagapattinam 611 002, India
[2]Department of Aquacultural Engineering, College of Fisheries Engineering,
Tamil Nadu Dr.J.Jayalalithaa Fisheries University, Nagapattinam 611 002, India
[3]Office of the Controller of Examinations,
Tamil Nadu Dr.J.Jayalalithaa Fisheries University, Nagapattinam 611 002, India

Abstract

This study presents the development, calibration, and application of low-cost portable colorimeters for the determination of copper and nickel in aqueous and brackish water samples. Three portable colorimeters were fabricated using Light Emitting Diodes (LEDs) with different wavelength ranges: Blue (BPC), Red (RPC), and Yellow (YPC). The performance of each device was evaluated using standard solutions of copper sulfate and nickel salts. Resistance values obtained from the devices were converted to absorbance values using a derived resistance–absorbance relationship, and calibration curves were established. For copper analysis, the Red LED colorimeter (610–720 nm) demonstrated high sensitivity and a strong linear relationship with a correlation coefficient (R^2) of 0.993. For nickel detection, the Yellow Portable Colorimeter (YPC) with a wavelength range of 570–600 nm exhibited the best performance, showing a linear correlation with $R^2 = 0.97986$ in the concentration range of 0.02 to 0.1 ppm. The BPC and RPC showed poor correlations and were deemed unsuitable for nickel estimation. The practical applicability of the YPC was further validated through onsite analysis of brackish water samples from the Vettar River in Nagapattinam. The average nickel concentration was found to be 0.06 ± 0.007 ppm. The developed devices, each costing less than 5 USD, offer an affordable, portable, and user-friendly solution for field-based heavy metal analysis in water.

Keywords: Portable colorimeter; copper; water sample; LED; Aquaculture

***Correspondence**
Author: Kesavan Devarayan
Email: kesavan@tnfu.ac.in

Introduction

The testing of nickel and copper in aquaculture water is crucial due to their significant environmental and ecological ramifications. High concentrations of heavy metals, including nickel and copper, pose threats to aquatic ecosystems. These metals, stemming from both natural and anthropogenic sources, can disrupt water quality, affect biodiversity, and alter the ecological balance within aquatic systems (Tabassum et al., 2024).

Copper, for instance, plays a role as a micronutrient necessary for the growth of aquatic organisms; however, excessive levels can be detrimental. Overexposure to copper can cause physiological and developmental issues in aquatic life, influencing various species differently depending on their sensitivity to metal concentrations (Albou et al., 2024). Nickel, similarly, is a pollutant whose elevated presence in aquatic environments can severely impact the health of these systems, affecting both flora and fauna (Hong et al., 2020).

Monitoring and regulating the levels of nickel and copper are essential to protect aquatic environments. This need stems from their potential to cause bioaccumulation and biomagnification, where these metals accumulate through the food chain, leading to harmful concentrations in top predators, which can have cascading effects on ecosystem health (Hong et al., 2020).

Additionally, maintaining appropriate levels of these metals is vital not just for ecological health but also for human health and safety, given that aquaculture produces food consumed by humans. Contaminated water can affect the quality and safety of aquatic food products, necessitating rigorous testing and management practices in aquaculture water systems (Albou et al., 2024).

In aquaculture practices, farmers frequently rely on reagent-based colorimetric kits for assessing water quality parameters like pH, dissolved oxygen, and nitrite due to their ease of use and affordability (Kathavarayan et al., 2019). Similarly, colorimetric methods have been extended for the detection of heavy metals such as copper and nickel, which are increasingly relevant due to their toxic effects on aquatic organisms even at trace concentrations. These kits often use chelating or complexing agents that react specifically with metal ions, resulting in a visible color change. For example, copper may develop a blue or violet hue depending on its concentration, while nickel may produce shades of green. These color changes are then compared against a standard chart to estimate metal concentration.

However, a significant limitation arises from the reliance on human visual perception to distinguish between closely similar shades. Slight variations in copper or nickel concentrations can lead to subtle color differences—such as a faint change from light blue to deep blue or greenish-blue—making it difficult for users to interpret results accurately. This subjectivity can lead to under- or overestimation of metal levels, which is critical since even small deviations can impact fish health and water safety.

Moreover, aquaculture pond water is a complex matrix containing a mix of organic matter (from uneaten feed, fish excreta, and decaying biomass), microorganisms, plankton, and suspended solids. These components can lead to biofouling and optical interference, potentially compromising the accuracy of color-based or contact-based metal detection techniques (Cook et al., 2007; Sander et al., 2009). The accumulation of such substances on sensors or within test vials can alter or mask the true color response.

To overcome these challenges, there is a growing need for more precise, sensitive, and interference-resistant methods for detecting heavy metals in aquaculture. Colorimetry remains a promising non-contact analytical technique, particularly when enhanced with digital image processing, smartphone integration, or optical sensors that minimize human error and improve resolution between closely spaced concentration ranges.

Despite the growing importance of monitoring heavy metals in aquaculture, very limited studies have explored the colorimetric determination of parameters like pH (Tucker et al., 1989; Lopez-Ruiz et al., 2014), and even fewer have addressed the detection of metals such as copper and nickel using accessible, field-deployable colorimetric tools. However, colorimetry has been successfully applied for evaluating a variety of water quality indicators—including chromium, nickel, fluoride, nitrite, nitrate, iron, and dissolved oxygen—using various innovative colorimeter models.

Some simple designs like the graduated cylinder colorimeter (Gordon et al., 2002) and the Lego colorimeter (Asheim et al., 2014) employ only basic components: a light source and a detector to measure light transmittance through a colored solution. More advanced versions, such as the three-LED-based colorimeter for pollution detection (Chi et al., 2021) and portable multi-sample colorimeters (Anzalone et al., 2013), incorporate adjustable wavelength light sources, microcontrollers, and embedded software systems for improved sensitivity and functionality (Braga et al., 2017).

Smartphone-based colorimeters have also emerged, leveraging built-in cameras and applications to extract RGB pixel values for analyte detection. For example, Masawat et al. (2015) demonstrated a tetracycline-based colorimetric method using a phone camera, while Sumriddetchkajorn et al. (2013) developed a mobile chlorine monitoring system. Although innovative, these systems often involve expensive components, multi-step sample processing, or require technical expertise, which limits their usability in rural or small-scale aquaculture operations.

To overcome these limitations, Devarayan et al. (2023) recently reported the development of a portable and cost-effective colorimeter for nitrite detection, which delivered accurate results comparable to commercial instruments. This advancement highlights the potential of compact, user-friendly devices for on-site water quality analysis.

Traditionally, digital or pen-type pH meters are used in aquaculture farms, functioning on electrochemical principles. However, these instruments are vulnerable to biofouling, drift, and inconsistent readings, particularly in complex pond water matrices rich in organic matter and microbial content. They also demand regular calibration, careful maintenance, and operator training.

In this context, the current study focuses on developing a simple, reagent-based colorimetric detection system specifically for copper and nickel in aquaculture water. The system integrates a portable colorimeter and a metal-specific chromogenic reagent, guided by the following design principles: (i) Portability for easy field use, (ii) Digital display with reliable and accurate output, (iii) Cost-effectiveness and ease of operation, (iv) On-site compatibility for real-time decision-making in farm environments.

This approach aims to empower aquaculture practitioners with a practical, low-cost, and rapid method for monitoring heavy metal contamination, ultimately contributing to better water management and fish health.

Experimental

Materials

A red light-emitting diode (LED) was employed as the light source, while a light-dependent resistor (LDR) served as the optical detector. The circuit included a 1 kΩ carbon film resistor with 5% tolerance for current regulation.

Additional components used in the setup included an ON/OFF switch, acrylic sheet for structural support, a digital multimeter for voltage and resistance measurements, and a 9-volt battery for power supply. The chemicals used for the colorimetric detection of copper and nickel-copper(II) sulfate, nickel(II) chloride, and dimethylglyoxime (DMG)—were procured from Himedia Laboratories Pvt. Ltd., India.

Fabrication of portable colorimeter

The fabrication of the portable colorimeter was carried out following a procedure similar to that described by Devarayan et al. (2024), Devarayan et al. (2025). Briefly, a red LED was used as the light source, with its negative terminal connected to a 1 kΩ resistor, and both terminals subsequently connected to a 9-volt battery. An ON/OFF switch was integrated into the circuit to control the LED power supply (Figure 1).

The light-dependent resistor (LDR), functioning as the optical detector, was directly connected to the input terminals of a digital multimeter circuit board. No additional resistors were used for the LDR, as it directly transmits resistance-based input values for digital readout.

A rectangular optical compartment (7 cm × 2 cm × 2 cm) was constructed using a white acrylic sheet. The LED and LDR were mounted on opposite ends (180° apart) of the compartment - each positioned 2 cm from their respective sides. The top surface of the compartment included two circular openings (diameter: 1.2 cm) that served as cuvette holders - one near the LED for the blank solution, and one near the LDR for the sample solution. The distances between the LED and the blank cuvette center, and between the LDR and the sample cuvette center, were kept identical to ensure optical alignment and minimize measurement errors.

To eliminate ambient light interference, the entire optical chamber was enclosed using black insulating tape or coated with black paint. The fabricated optical box was then integrated with the digital display unit of the multimeter, creating a compact, portable colorimeter suitable for handheld or pocket use.

Depending on the light source used, the device variants were designated as: YPC – Yellow LED-based Portable Colorimeter; RPC – Red LED-based Portable Colorimeter; BPC – Blue LED-based Portable Colorimeter.

This modular design allows flexibility in selecting different wavelengths for targeted colorimetric analysis of specific analytes such as copper and nickel in aquaculture water.

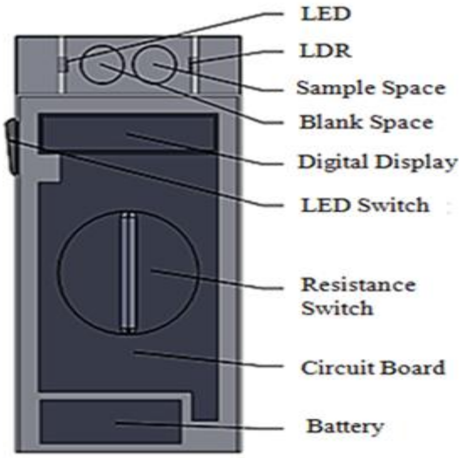

Figure 1. Schematic three-dimensional view of developed portable colorimeter.

Operating procedure

The working principle of the portable colorimeter is based on the Beer–Lambert law, which relates the absorbance of light to the properties of the material through which the light passes. In this system, light emitted from a red LED passes through the sample solution, and the transmitted light is detected by a light-dependent resistor (LDR). The LDR's resistance value, which varies with the intensity of the transmitted light, is displayed on a digital multimeter.

As the concentration of the analyte increases, more light is absorbed by the solution, resulting in less transmitted light reaching the LDR. Consequently, the LDR exhibits a higher resistance value. Thus, there is a direct relationship between the analyte concentration and the measured resistance, with higher resistance values indicating higher concentrations.

In this system, resistance values are used in place of conventional transmittance readings. The resistance of the blank solution (R_blank) represents 100% transmittance. The resistance of the sample solution (R_sample) is used to compute the absorbance, which is inversely proportional to transmittance. The absorbance (A) is calculated using the modified Beer–Lambert equation:

$$A = -\log \frac{T}{T_o} = -\log \frac{R_{Blank}}{R_{Sample}} \qquad (1)$$

Where, R_{blank} is the resistance value for the blank (reference) solution and R_{sample} is the resistance value for the sample solution.

A calibration curve is constructed by plotting absorbance versus the concentration of known standard solutions. This graph is then used to determine the concentration of the analyte in unknown aquaculture water samples based on their measured absorbance.

Calibration of the colorimeter for the estimation of copper

The standard copper sulphate solutions from 0.05 M to 1.0 M were prepared. 2 mL of these standard solutions were taken in a cuvette and it is tested in the developed colorimeter. The resistance values are noted and a calibration graph is plotted with resistance and absorbance value for different concentrations of the standard solutions prepared. The concentration of copper in an unknown sample is determined by comparing it with the calibration graph using the absorbance or resistance values.

Calibration of the Colorimeter for Copper Estimation

To calibrate the portable colorimeter for copper analysis, standard copper(II) sulfate solutions ranging from 0.05 M to 1.0 M were prepared. A 2 mL aliquot of each standard solution was transferred into a cuvette and analyzed using the developed colorimetric device. For each concentration, the corresponding resistance values were recorded from the digital display.

Using these resistance readings, the absorbance values were calculated based on the Beer–Lambert law, as described earlier. A calibration curve was then constructed by plotting absorbance (or resistance) against the known concentrations of the standard copper solutions.

This calibration graph serves as a reference to determine the concentration of copper in unknown aquaculture water samples. By measuring the sample's resistance (or absorbance) using the colorimeter, the copper concentration can be estimated by interpolating the value from the calibration plot.

Determination of Copper in an Unknown Sample

To evaluate the performance of the developed portable colorimeter, an unknown copper-containing sample was prepared by mixing two standard copper(II) sulfate solutions of known concentrations. A 2 mL aliquot of the unknown solution was placed in a cuvette and analyzed using the fabricated colorimeter.

The corresponding resistance value was recorded and used to calculate the absorbance. This value was then compared against the calibration graph established earlier. By interpolating the absorbance (or resistance) value on the calibration curve, the concentration of copper in the unknown sample was accurately determined.

On-site Determination of Nickel in Brackish Water Sample

An on-site analysis was conducted to determine the nickel concentration in a brackish water sample collected from the Vettar River at Nagore, Nagapattinam. The procedure followed was similar to the calibration protocol established earlier. A 2 mL aliquot of the water sample was placed in a cuvette and analyzed using the developed portable colorimeter.

The resistance value obtained from the device was recorded and subsequently converted into absorbance using the Beer–Lambert equation. This absorbance (or resistance) value was then compared with the pre-established calibration curve for nickel. By interpolation, the nickel concentration in the brackish water sample was accurately determined on-site.

Results and discussion

Three portable colorimeters were successfully developed, each equipped with a different light source—yellow, red, and blue LEDs—to evaluate their performance across various analytes. For the estimation of copper, standard copper(II) sulfate solutions were used to calibrate the devices. The performance of the developed colorimeters was compared against a commercial laboratory-grade colorimeter using the same set of standard solutions.

To determine the concentration of unknown samples, the following formula based on the Beer–Lambert law was used:

$$C_2=C_1\times(A_2/A_1) \qquad (2)$$

Where, C_2 = Concentration of the unknown sample; C_1 = Concentration of the standard solution; A_1 = Absorbance of the standard solution; A_2 = Absorbance of the unknown sample.

The absorbance of the standard copper solutions was first measured using a commercial colorimeter at multiple wavelengths: 420 nm, 440 nm, 490 nm, 520 nm, 540 nm, 570 nm, 600 nm, and 720 nm. These readings served as reference values.

The same set of standard solutions was then tested using the developed portable colorimeters. Calibration curves were generated by plotting absorbance (or resistance) values against known concentrations for each LED-based system. The linearity and correlation of these calibration curves were analyzed and compared to those from the commercial system to validate the accuracy and reliability of the portable devices.

The results demonstrated that the developed portable colorimeters produced comparable trends and reliable concentration estimations when matched against the commercial equipment. This confirms the suitability of the portable system for field-level water quality monitoring, especially in resource-limited settings.

Calibration of the Colorimeter for Estimation of Copper

The Red LED-based Portable Colorimeter (RPC), operating within a wavelength range of 610 to 720 nm, was calibrated for copper analysis using standard copper(II) sulfate solutions. Each prepared standard solution was analyzed in the RPC, and the corresponding resistance values were recorded. These resistance values were then converted into absorbance values using the modified Beer–Lambert equation.

All the calculated absorbance values were positive, confirming the optical sensitivity of the RPC within the red light region and its suitability for copper detection. Subsequently, a calibration graph was constructed by plotting the concentration of the standard copper solutions on the x-axis against the corresponding absorbance and resistance values on the y-axis. The calibration plot exhibited a consistent trend, demonstrating the ability of the developed colorimeter to reliably detect varying concentrations of copper. This validated the functionality of the RPC for potential use in on-site water quality assessment in aquaculture environments.

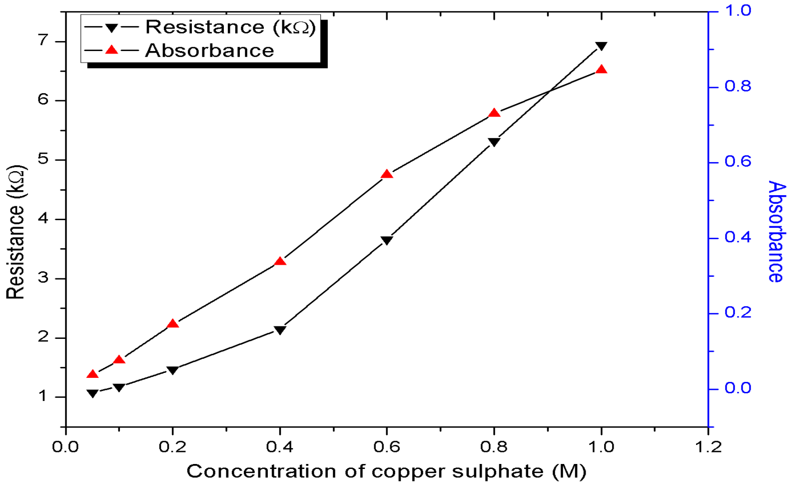

Figure 2. Correlation between the concentration of copper sulphate standard solution vs resistance and absorbance of the developed RPC.

Figure 2 illustrates the correlation between the concentration of copper(II) sulfate and the corresponding resistance and absorbance values measured using the developed portable colorimeter. The resistance curve closely aligns with the absorbance curve, indicating a strong relationship between the two parameters. Both curves exhibit a linear trend with respect to copper concentration, confirming that the colorimeter provides consistent and reliable measurements across the tested range.

Figure 3 depicts the correlation between the concentration of copper(II) sulfate solution and the corresponding absorbance values obtained using the portable colorimeter. The calibration curve demonstrates a strong linear relationship, with a correlation coefficient (R^2) of 0.993, indicating the high accuracy and reliability of the colorimetric measurement for copper estimation.

Calibration of the Commercial Colorimeter for Copper Determination

The same standard copper(II) sulfate solutions were tested using a commercial colorimeter to evaluate its performance and compare it with the developed portable device. Among the various wavelengths tested, 600 nm was identified as the most suitable for the determination of copper concentration, as it yielded consistent and reliable absorbance readings. Other tested wavelengths either produced negative absorbance values or showed no significant variation, rendering them unsuitable for accurate measurement.

To further validate the instrument, a 0.15 M copper solution, derived from the standard stock, was tested at 570 nm. Using Equation (2) from the Beer–Lambert-based calculation method, the average concentration of copper was determined to be 0.215 ± 0.214 ppm, demonstrating the instrument's sensitivity and limitations under certain conditions (Table 1).

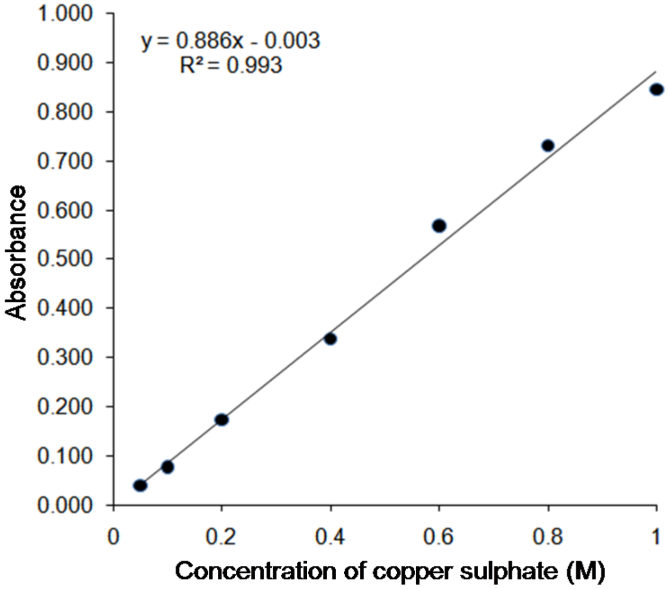

Figure 3. Graph showing the correlation coefficient value of absorbance with respect to the concentration of copper sulphate for developed RPC.

Calibration of the Portable Colorimeter for Nickel Determination

Table 1. Calibration of developed portable colorimeters and determination of copper concentration in unknown sample.

Molarity of copper sulphate solution (M)	Resistance(KΩ)			Absorbance		
	Blue	Yellow	Red	Blue	Yellow	Red
1	1.22	2.25	6.94	-0.014	0.335	0.846
0.8	1.19	1.92	5.32	-0.025	0.266	0.730
0.6	1.19	1.82	3.66	-0.025	0.243	0.568
0.4	1.15	1.5	2.15	-0.040	0.159	0.337
0.2	1.08	1.23	1.47	-0.067	0.073	0.172
0.1	1.06	1.09	1.18	-0.075	0.020	0.076
0.05	1.06	1.06	1.08	-0.075	0.008	0.038
0.01	1.03	1.01	0.96	-0.088	-0.013	-0.013
0.005	1.02	0.98	0.92	-0.092	-0.026	-0.032
0.001	1.02	0.98	0.91	-0.092	-0.026	-0.037
Unknown (0.15)	1.08	1.19	1.32	-0.067	0.059	0.125

For the determination of nickel, the Blue LED-based Portable Colorimeter (BPC), operating in the 450–500 nm wavelength range, was utilized. A series of standard nickel(II) chloride solutions of varying concentrations were prepared and tested using the BPC. The corresponding resistance values were recorded and subsequently converted to absorbance values.

A calibration graph was then plotted, showing the relationship between the concentration of nickel standard solutions and their respective absorbance and resistance values. The graph demonstrated a linear correlation, confirming that the BPC is effective for the colorimetric detection of nickel in aqueous solutions.

Figure 4 illustrates the correlation between the concentration of nickel standard solutions and the corresponding resistance and absorbance values obtained using the Blue LED-based Portable Colorimeter (BPC). The resistance and absorbance curves show a similar trend, with both values increasing as the concentration increases. However, despite this visual similarity, the calculated correlation coefficient was negative, indicating a poor linear relationship between absorbance and concentration.

This suggests that the BPC does not provide reliable quantitative data for nickel estimation. Furthermore, similar inconsistent results were observed when using the Red LED-based Portable Colorimeter (RPC) for nickel detection. Based on these findings, it can be concluded that both BPC and RPC are not suitable for the colorimetric determination of nickel under the tested conditions.

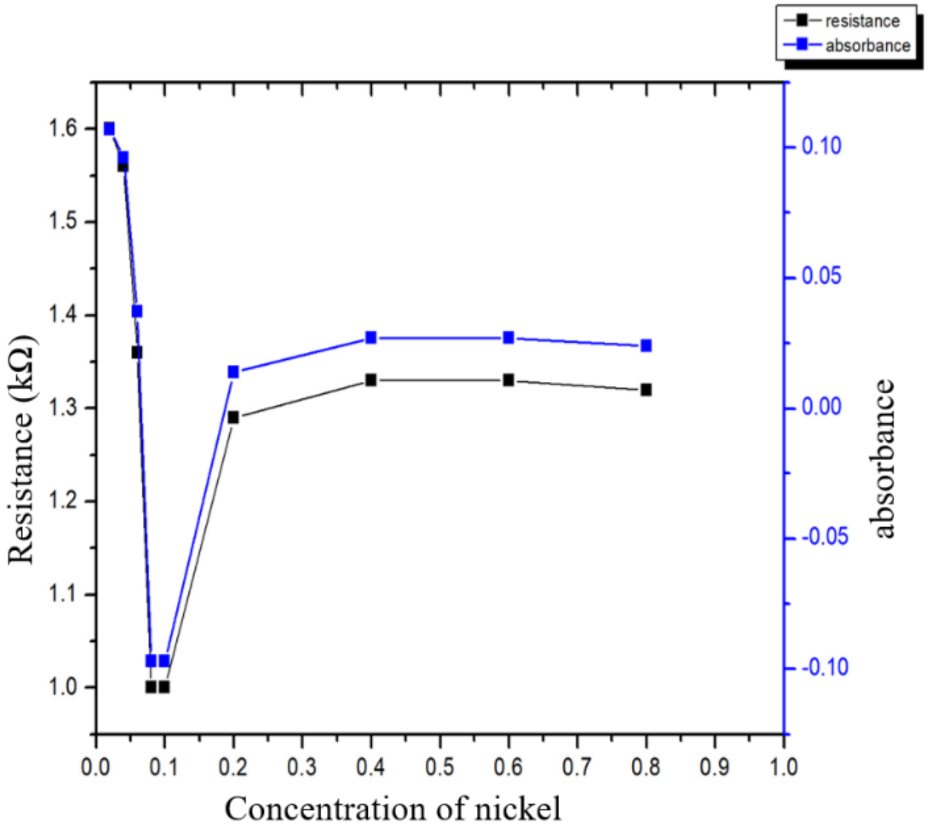

Figure 4. Correlation between concentration of nickel standard solution vs resistance and absorbance of the developed portable colorimeter BPC.

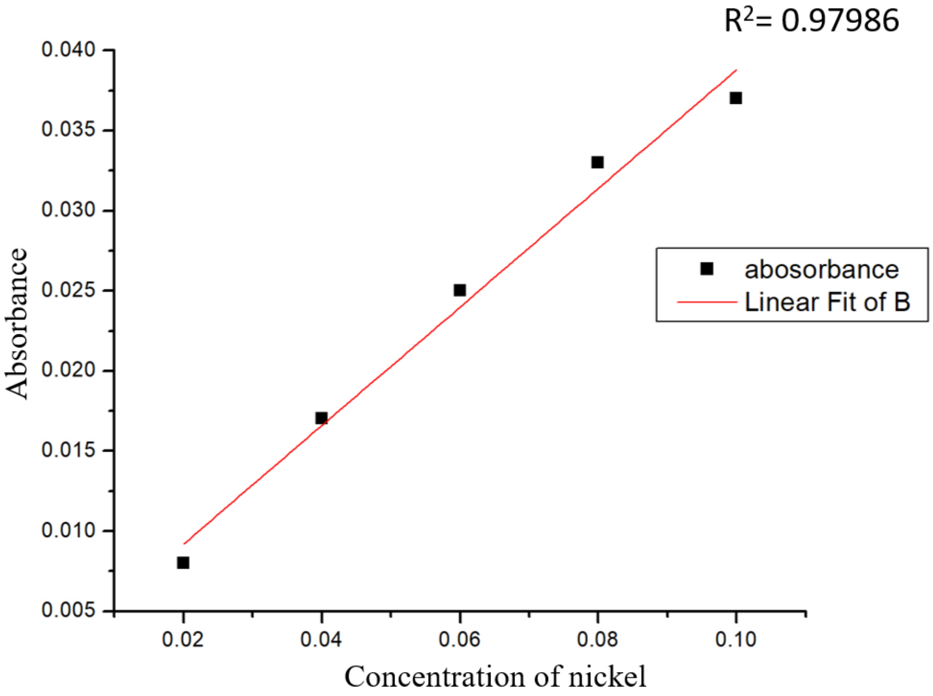

Figure 5. The correlation coefficient value of absorbance with respect to the concentration of nickel standard solution for developed YPC

Figure 5 presents the correlation between absorbance and the concentration of nickel standard solutions as measured by the Yellow LED-based Portable Colorimeter (YPC). The R^2 (correlation coefficient) value was found to be 0.97986 in the concentration range of 0.02 ppm to 0.1 ppm, indicating a strong linear relationship. This suggests that the YPC is well-suited for the quantitative determination of nickel within this concentration range.

The YPC operates within a wavelength range of 570 to 600 nm. During testing, it was observed that an increase in nickel concentration corresponded with a proportional increase in resistance values. In contrast to the RPC and BPC, which displayed poor or inconsistent linearity for nickel estimation, the YPC demonstrated a clear and consistent trend.

Therefore, it can be concluded that the YPC is suitable for the determination of nickel in unknown samples, particularly in the low concentration range of 0.02 ppm to 0.1 ppm, making it a promising tool for on-site monitoring of trace nickel in aquaculture water samples.

To further enhance the accuracy of copper estimation, the standard copper sulfate solutions were tested using a Red LED-based Portable Colorimeter, which operates within the wavelength range of 610 to 720 nm. The red LED was specifically selected as its emitted wavelength is complementary to the characteristic blue color of copper sulfate solutions, thereby ensuring maximum absorbance sensitivity and improved analytical response.

During calibration, the resistance values measured for the standard solutions were converted into absorbance values using a predefined resistance–absorbance relationship. The calibration curve demonstrated a strong linear relationship, as confirmed by a correlation coefficient (R^2) of 0.993, indicating excellent reliability and reproducibility of the measurements.

The concentration of unknown samples was determined using Equation (2) across multiple test samples yielded an average copper concentration of 0.149 ± 0.0125 ppm. The results were validated against the calibration curve, and the strong correlation coefficient confirms the accuracy and suitability of the Red LED-based colorimeter for on-site copper analysis.

Optimization and Onsite Determination of Nickel Using Portable Colorimeter

To evaluate the performance of the developed portable colorimeters for nickel detection, standard nickel sulfate solutions ranging from 0.02 ppm to 1 ppm were tested using three colorimeter prototypes: BPC (Blue Portable Colorimeter), RPC (Red Portable Colorimeter), and YPC (Yellow Portable Colorimeter). For each device, the resistance values recorded were converted into absorbance values using the established resistance–absorbance relationship.

Among the three, the Yellow Portable Colorimeter (YPC) exhibited superior performance in terms of linearity and sensitivity. A strong correlation coefficient ($R^2 = 0.97986$) was observed for the concentration range 0.02 ppm to 0.1 ppm, indicating high accuracy and suitability of YPC for low-concentration nickel estimation.

An unknown laboratory sample was analyzed using the YPC. The resistance value was recorded and used in Equation (2) to calculate the concentration. The average nickel concentration in the unknown sample was found to be 0.4 ± 0.042 ppm, demonstrating the applicability of YPC for analytical purposes.

To assess the onsite applicability of the YPC, water samples were collected from the brackish water environment of the Vettar River, Nagapattinam. Three samples were tested using the same procedure. Based on the absorbance derived from resistance measurements, the average nickel concentration was found to be 0.06 ± 0.007 ppm.

The YPC colorimeter, developed at a cost of less than 5 USD, offers an economical, portable, and user-friendly solution for the onsite determination of nickel in environmental water samples. Its affordability and effectiveness make it a practical tool for field-level environmental monitoring.

Conclusion

The present study successfully demonstrates the development, calibration, and application of cost-effective portable colorimeters for the determination of copper and nickel in aqueous solutions. The devices were fabricated using light-emitting diodes (LEDs) with specific wavelength ranges to match the absorption characteristics of the analytes.

Among the tested devices, the Red LED Portable Colorimeter proved effective for copper analysis, showing a high correlation coefficient ($R^2 = 0.993$), and was capable of accurately determining unknown copper concentrations. Similarly, the Yellow Portable Colorimeter (YPC) exhibited excellent linearity and sensitivity for nickel estimation within the concentration range of 0.02 ppm to 0.1 ppm, with a strong correlation coefficient ($R^2 = 0.97986$). Other colorimeter configurations (BPC and RPC) were found unsuitable for nickel detection due to poor correlation and inconsistent readings.

The YPC was further validated through onsite testing of brackish water samples from the Vettar River, Nagapattinam, successfully determining nickel concentrations with acceptable accuracy and precision. The overall cost of development for each portable unit was kept under 5 USD, highlighting the potential of this low-cost, easy-to-use tool for field-level water quality monitoring and resource-limited settings.

This work not only provides a practical alternative to expensive commercial instruments but also supports environmental and industrial applications where real-time and decentralized monitoring of heavy metals like copper and nickel is critical.

References

Albou, E. M., Abdellaoui, M., Ait Boughrous, A., & Abdaoui, A. (2024). Agricultural practices and their impact on aquatic ecosystems – A mini-review. *Ecological Engineering & Environmental Technology, 25*(1), 321–331.

Anzalone, G. C., Glover, A. G., & Pearce, J. M. (2013). Open-source colorimeter. *Sensors, 13*(4), 5338–5346.

Asheim, J., Kvittingen, E. V., Kvittingen, L., & Verley, R. (2014). A simple, small-scale Lego colorimeter with a light-emitting diode (LED) used as detector. *Journal of Chemical Education, 91*(7), 1037–1039.

Braga, M. S., Jaimes, R. F., Borysow, W., Gomes, O. F., & Salcedo, W. J. (2017). Portable multispectral colorimeter for metallic ion detection and classification. *Sensors, 17*(8), 1730.

Chi, H. B. L., Khanh, D. N. N., Vy, N. T. T., Hanh, P. X., Vu, T. N., Lam, H. T., & Phuong, N. T. K. (2021). Development of a low-cost colorimeter and its application for determination of environmental pollutants. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 249*, 119212.

Cook, P. L., & Austen, R. A. (2007). The effect of biofouling on pH and dissolved oxygen measurements using in situ sensors. *Continental Shelf Research, 27*(3), 472–485.

Devarayan, K., Kathavarayan, M., Theivasigamani, A., Sukumaran, M., & Kandasamy, S. (2023). Development of portable colorimeter for on-site determination of water quality in aquaculture. *Pigment & Resin Technology, ahead-of-print.*

Devarayan, K., John, E. U. S., Mohan, G., Palanisamy, Y., Theivasigamani, A., Sukumaran, M., Marimuthu, R., & Jayaseelan, S. S. (2024). Development of portable colorimeter for detection of formalin in fish. *Revista de Chimie*, *75*(2), 11–16.

Devarayan, K., Muthurani, D. A., Kannusamy, G., Theivasigamani, A., Palanisamy, Y., Mohan, G., Sukumaran, M., Siluvai John, E. U., Marimuthu, R., & Anjappan, H. (2025). On-site colorimetric determination of pH in brackish water aquaculture. *Pigment & Resin Technology*, *54*(3), 461–466.

Gordon, J., & Harman, S. (2002). A graduated cylinder colorimeter: An investigation of path length and the Beer-Lambert law. *Journal of Chemical Education, 79*(5), 611.

Hong, Y.-J., Liao, W., Feng, C.-L., Xu, Z.-X., Bai, Y.-C., Yan, Z.-F., & Xu, D.-Y. (2020). Progress in the research of the toxicity effect mechanisms of heavy metals on freshwater organisms and their water quality criteria in China. *Journal of Chemistry, 2020*, 1–12.

Kathavarayan, M., Motcham, V. V., Anjappan, H., & Devarayan, K. (2019). Progress in development of portable colorimeters for on-site analyses. *Chemical Science Review and Letters, 8*, 91–99.

Lopez-Ruiz, N., Curto, V. F., Erenas, M. M., Benito-Lopez, F., Diamond, D., Palma, A. J., & Capitan-Vallvey, L. F. (2014). Smartphone-based simultaneous pH and nitrite colorimetric determination for paper microfluidic devices. *Analytical Chemistry, 86*(19), 9554–9562.

Masawat, P., Harfield, A., & Namwong, A. (2015). An iPhone-based digital image colorimeter for detecting tetracycline in milk. *Food Chemistry, 184*, 23–29.

Sander, S. G., & Gendron, F. (2009). Biofouling effects on pH sensor performance in seawater. *Environmental Science & Technology, 43*(2), 357–361.

Sumriddetchkajorn, S., Chaitavon, K., & Intaravanne, Y. (2013). Mobile device-based self-referencing colorimeter for monitoring chlorine concentration in water. *Sensors and Actuators B: Chemical, 182*, 592–597.

Tabassum, S., Kotnala, C. B., Salman, M., Tariq, M., Khan, A. H., & Khan, N. A. (2024). The impact of heavy metal concentrations on aquatic insect populations in the Asan Wetland of Dehradun, Uttarakhand. *Scientific Reports, 14*(1).

Tucker, S., Robinson, R., Keane, C., Boff, M., Zenko, M., Batish, S., & Street, K. W. (1989). Colorimetric determination of pH. *Journal of Chemical Education, 66*(9), 769.

Publication History

Received	28.07.2025
Revised	15.08.2025
Accepted	30.08.2025
Online	15.09.2025