Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

An Accurate Sensing Technique for Estimation and Detection of Cr (Iii) In Water By using Smartphone

[1]Mr. D. JAGAN
Asst. Professor – Department of Civil Engineering
JNTUH University College Of Engineering, Sultanpur

[2]M. CHANDANA, M. RAMESH, P. ASHWINI, R. JANANI
Students – Department of Civil Engineering
JNTUH University College Of Engineering, Sultanpur

[3]Dr. S. M. SWAMY
Associate Professor – Department of Mechanical Engineering,
G. Narayanamma Institute of Technology and Science(Autonomous), Hyderabad.

ABSTRACT: Hexavalent chromium (Cr^{6+}) contamination in water poses serious environmental and public health concerns, creating a need for rapid and reliable detection methods. This study presents a low-cost, portable smartphone-based colorimetric sensing technique for estimating chromium concentration in water samples. A selective reagent reacts with chromium ions to produce a color change, which is captured using a smartphone camera under controlled lighting conditions. RGB (Red, Green, Blue) values extracted through image processing are correlated with known chromium concentrations to develop a calibration model for quantitative analysis. The proposed method demonstrates good sensitivity, accuracy, and reproducibility within the tested concentration range. Compared with conventional techniques such as Atomic Absorption Spectroscopy (AAS) and ICP-MS, it offers advantages including low cost, simplicity, rapid analysis, and on-site applicability. The developed system provides an effective tool for real-time water quality monitoring, particularly in resource-limited areas, and can support environmental monitoring, industrial wastewater assessment, and public health protection.

Key words: Chromium detection, hexavalent Chromium, Smart phone-based sensing, Colorimetric analysis, Calibration model, Digital image analysis

1. INTRODUCTION

Water is an essential natural resource for all living organisms. However, rapid industrialization, urbanization, and population growth have significantly increased water pollution worldwide. Among various contaminants, heavy metals are of particular concern due to their toxicity, persistence, and bioaccumulation in living systems. Chromium is extensively used in industries such as electroplating, leather tanning, textile dyeing, and metal finishing. Consequently, chromium-containing wastewater is often discharged into water bodies, leading to contamination of surface and groundwater resources. Therefore, there is a growing demand for simple, rapid, and cost-effective methods that can be employed for on-site water quality assessment. This project proposes a smartphone-based sensing technique using silver nanoparticles for the detection and estimation of Cr(III) ions in water. The method utilizes a colorimetric approach, where changes in sample color are captured using a smartphone camera and analyzed through RGB image processing. The developed system aims to provide an affordable, portable, and reliable solution for real-time chromium monitoring.

1.1. Objectives

- Synthesize silver nanoparticles for sensing applications.
- Detect Cr(III) ions using a colorimetric method.
- Capture sample images using a smartphone camera.
- Extract and analyze RGB values from the images.
- Develop a calibration curve for quantitative estimation.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

- Evaluate the accuracy, sensitivity, and reliability of the proposed method.

Fig 1: The Chromium cycle in Environment

Zhao et al. (2012) developed a gold nanoparticle (AuNP)-based colorimetric assay for detecting Cr(III) ions in water. The presence of Cr(III) induced nanoparticle aggregation, producing a visible color change from red to blue.

Karim et al. (2016) investigated the toxicity mechanisms of chromium in biological systems and highlighted the importance of developing accurate and reliable detection methods to minimize environmental and health risks.

Duan et al. (2017) developed a coordination chemistry-based nanoprobe for chromium sensing. Their approach demonstrated high sensitivity and showed strong potential for environmental monitoring applications.

Xia et al. (2019) designed modified gold nanoparticles for the selective detection of Cr(III) ions. The sensing system exhibited enhanced stability, high selectivity, and minimal interference from other metal ions.

1.2. RESEARCH GAP

Although significant progress has been made in chromium detection, several challenges remain. Conventional analytical techniques are often expensive, complex, and unsuitable for field applications. While nanoparticle-based colorimetric methods provide simpler alternatives, some suffer from limited precision and interference effects. Recent smartphone-assisted sensing approaches have demonstrated promising results; however, further improvements in image processing and quantitative analysis are required.

1.3. PRESENT WORK

The present study addresses these limitations by integrating a smartphone-based sensing system with MATLAB-based RGB image analysis for the detection and estimation of Cr(III) ions in water. The proposed method is simple, cost-effective, portable, and suitable for real-time water quality monitoring. By utilizing colorimetric sensing, RGB analysis, and calibration techniques, the study aims to provide an accurate and reliable alternative to conventional chromium detection methods.

1.4. MATERIALS USED

The successful completion of this project required a combination of chemicals, laboratory equipment, and digital tools for the detection and analysis of Cr(III) ions in water samples.

Chromium(III) stock solution, prepared from chromium chloride ($CrCl_3$), was used as the source of Cr^{3+} ions for preparing samples of varying concentrations. Accurate preparation and dilution of the stock solution ensured reliable calibration and analysis.

Silver nanoparticles (AgNPs) served as the sensing material due to their unique optical properties and strong surface plasmon resonance. The interaction between AgNPs and Cr(III) ions produced a visible color change, forming the basis of the colorimetric detection method.

Distilled water was used for all solution preparations and dilutions to prevent interference from impurities and maintain consistency throughout the experiment.

Laboratory apparatus such as measuring cylinders, micropipettes, beakers, test tubes, and glass rods were used for solution preparation and handling. Measuring cylinders facilitated the preparation of larger volumes, while micropipettes ensured precise measurement of small quantities. Clean test tubes or cuvettes were used to hold samples during the reaction and image-capturing process.

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International Journal of Engineering Research & Technology (IJERT)
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For data acquisition and analysis, a smartphone equipped with a high-resolution camera was used to capture images of the prepared samples. The smartphone provided a portable and cost-effective alternative to conventional optical instruments. Image processing and RGB value extraction were performed using MATLAB software installed on a computer system.

MATLAB enabled accurate analysis of color variations and conversion of image data into quantitative information. All materials were handled following standard laboratory procedures to ensure accuracy, reliability, and reproducibility of the results.

Heating mantle

Distilled water

Water Samples

$K_2Cr_2O_4$

Beakers,

Tri Sodium citrate

Fig 2: Materials required

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International Journal of Engineering Research & Technology (IJERT)
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2. METHODOLOGY

Flow Chart

Collection of Water Samples

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Filtration and Pre-treatment of Samples

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Preparation of Standard Cr(III) Solutions with Known Concentrations

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Synthesis of Silver Nanoparticles (AgNPs)

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Addition of AgNPs to Standard Solutions and Water Samples

↓

Incubation for Complete Color Development

↓

Image Acquisition Using a Smartphone Camera Under Controlled Lighting Conditions

↓

Import of Images into MATLAB

↓

Image Pre-processing (Cropping and Resizing)

↓

RGB Value Extraction and Color Intensity Analysis

↓

Development of Calibration Curve

↓

Determination of Cr(III) Concentration in Unknown Samples

↓

Validation, Result Interpretation, and Reporting

2.1. Preparation of Silver Nanoparticles (AgNPs)

The synthesis of silver nanoparticles (AgNPs) is a crucial step in this study, as their optical properties directly influence the sensitivity and performance of the sensing system. AgNPs were prepared using the chemical reduction method, in which silver ions from silver nitrate ($AgNO_3$) were reduced to metallic silver using sodium borohydride ($NaBH_4$) as the reducing agent.

Initially, a silver nitrate solution of known concentration was prepared by dissolving $AgNO_3$ in distilled water. A freshly prepared sodium borohydride solution was then added dropwise to the silver nitrate solution under continuous stirring. As the reduction reaction progressed, the solution changed from colorless to pale yellow and finally to bright yellow, indicating the formation of silver nanoparticles. This color change is attributed to the Surface Plasmon Resonance (SPR) effect of AgNPs.

The size, shape, and stability of the nanoparticles depend on factors such as reactant concentration, temperature, stirring rate, and addition rate of the reducing agent. Proper control of these parameters ensured the formation of stable and uniformly dispersed nanoparticles. Stabilizing agents may also be used to minimize aggregation and improve nanoparticle stability. The synthesized nanoparticles were stored under appropriate conditions to prevent degradation and maintain their sensing performance.

2.2 Preparation of Cr(III) Solutions

Standard Cr(III) solutions were prepared to develop a calibration curve and evaluate the sensing performance of the proposed method. Chromium chloride ($CrCl_3$) was used as the source of Cr^{3+} ions.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

A stock solution was prepared by accurately weighing a known quantity of $CrCl_3$ and dissolving it in distilled water. From this stock solution, a series of standard solutions with different concentrations were prepared using the dilution method. Concentrations such as 0 ppm, 5 ppm, 10 ppm, and 20 ppm were selected to establish a suitable calibration range.

All dilutions were carried out using volumetric flasks and pipettes to ensure high accuracy. The prepared solutions were thoroughly mixed and labeled properly to avoid confusion during experimentation. Clean glassware rinsed with distilled water was used throughout the process to prevent contamination.

The prepared Cr(III) solutions served as reference standards for studying their interaction with silver nanoparticles. The resulting color changes were analyzed to develop a calibration curve and determine the sensitivity and detection capability of the smartphone-based sensing system.

Sample	**Required Cr (ppm)**	**Cr Stock Added**	**AgNP Added**	**Sample water added**
Blank	0 ppm	0 ml	1 ml	10 ml
Sample 1	0.1 ppm	1 ml	1 ml	9 ml
Sample 2	0.2 ppm	2 ml	1 ml	8 ml
Sample 3	0.3 ppm	3 ml	1 ml	7 ml
Sample 4	0.4 ppm	4 ml	1 ml	6 ml

Table 1: Composition of Calibration Samples

3. EXPERIMENTAL SETUP

The experimental setup was designed to provide a simple, cost-effective, and portable method for the detection of Cr(III) ions using silver nanoparticles (AgNPs). A fixed volume of AgNP solution was transferred into a clean test tube or cuvette, followed by the addition of a measured volume of Cr(III) solution of known concentration. The mixture was gently stirred to ensure uniform interaction between the nanoparticles and chromium ions.

The reaction mixture was allowed to stand for a specified incubation period to facilitate complete color development. Initially, the AgNP solution exhibited a yellow color, which gradually changed depending on the concentration of Cr(III) ions present. The observed color variation served as a preliminary indication of chromium concentration.

To maintain consistency and reliability, all experiments were conducted under controlled conditions. A uniform light source and a white background were used throughout the study. Multiple samples with varying chromium concentrations were analyzed simultaneously to compare color intensity and establish the relationship between concentration and color change.

The simplicity of the setup eliminates the need for sophisticated instrumentation, making the technique suitable for both laboratory and field applications.

3.1 Image Capture and Data Acquisition

Image capture is a crucial step in the proposed methodology, as it enables quantitative analysis through RGB color extraction. A smartphone equipped with a high-resolution camera was used to capture images of the samples after complete color development.

To ensure reproducibility, all samples were placed on a white background under controlled LED illumination. The distance between the smartphone camera and the samples, as well as the camera angle, was kept constant throughout the experiment. Camera settings such as focus, exposure, and white balance were fixed to minimize image-to-image variations.

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International Journal of Engineering Research & Technology (IJERT)
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The captured images were imported into MATLAB for further analysis. A Region of Interest (ROI), typically the central portion of each sample, was selected to avoid edge effects and improve measurement accuracy. MATLAB was then used to extract the Red, Green, and Blue (RGB) intensity values from the selected region.

The extracted RGB data were systematically recorded and correlated with the corresponding chromium concentrations. Among the RGB components, the red intensity exhibited the most significant variation and was used for calibration and quantitative analysis.

The combination of smartphone-based image acquisition and MATLAB processing provides a portable, user-friendly, and reliable approach for estimating Cr(III) concentrations in water samples. This methodology effectively transforms visual color changes into numerical data, enabling accurate and real-time water quality assessment.

4. XPERIMENTAL WORK

4.1 Procedure

The experimental work for the detection and estimation of Cr(III) ions in water was carried out using silver nanoparticles (AgNPs) and smartphone-based image analysis. Initially, silver nanoparticles were synthesized by the chemical reduction of silver nitrate using sodium borohydride as the reducing agent. The formation of AgNPs was confirmed by the appearance of a bright yellow color due to the Surface Plasmon Resonance (SPR) effect.

Standard Cr(III) solutions of varying concentrations (0, 5, 10, 15, and 20 ppm) were prepared from a stock solution using distilled water and standard dilution techniques. A fixed volume of each chromium solution was then mixed with a fixed volume of AgNP solution in separate test tubes and allowed to react for a specified incubation period.

The interaction between Cr(III) ions and AgNPs resulted in visible color changes that varied with chromium concentration. After complete color development, images of all samples were captured using a smartphone camera under controlled lighting conditions. A white background, constant illumination, and fixed camera distance were maintained throughout the experiment to ensure consistency.

The captured images were subsequently analyzed using MATLAB software to extract RGB values for quantitative assessment of chromium concentration.

4.2 Observations

The synthesized AgNP solution exhibited a uniform yellow color, indicating the formation of stable and well-dispersed nanoparticles. Upon the addition of Cr(III) ions, noticeable color changes were observed due to the interaction between chromium ions and silver nanoparticles.

At lower chromium concentrations, only slight variations in color intensity were observed. As the concentration increased, the solution color gradually changed from yellow to light orange and then to reddish-brown shades. The intensity of the color change increased with increasing Cr(III) concentration.

The observed color variation is attributed to the aggregation of silver nanoparticles induced by Cr(III) ions. This aggregation alters the optical properties of the nanoparticles, resulting in a measurable shift in color intensity. It was also noted that consistent lighting conditions and camera positioning were essential for obtaining reliable and reproducible results.

These observations confirmed the suitability of AgNPs as colorimetric sensors for the detection of Cr(III) ions in water samples.

4.3 Data Collection

Following image acquisition, the samples were analyzed using MATLAB-based image processing techniques. For each image, a Region of Interest (ROI) was selected from the central portion of the sample to minimize the effects of reflections and shadows.

The RGB (Red, Green, and Blue) intensity values were extracted from the selected region and recorded systematically along with the corresponding Cr(III) concentrations. To improve measurement reliability, multiple readings were taken for each sample, and the average RGB values were calculated.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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The collected data were organized in tabular form and used to construct a calibration curve by plotting chromium concentration against the corresponding red intensity values. The calibration curve served as a reference for determining the concentration of unknown water samples.

The systematic collection and analysis of RGB data enabled accurate quantification of Cr(III) ions and demonstrated the effectiveness of the proposed smartphone-based sensing method for water quality monitoring.

Fig 3. Colorimetric Analysis of Water Samples at different Cr concentrations

5. RE ULTS AND ANALYSIS

5.1 RGB Extraction

After image acquisition, the Red, Green, and Blue (RGB) intensity values were extracted from each sample image to quantify the color changes resulting from the interaction between Cr(III) ions and silver nanoparticles. RGB values represent the color composition of an image and serve as important parameters for quantitative analysis.

A Region of Interest (ROI) was selected from the central portion of each sample image to minimize the effects of reflections, shadows, and edge variations. The average RGB values within the selected region were extracted using image processing tools and recorded for each chromium concentration.

The extracted RGB data were tabulated and analyzed to identify variations corresponding to different Cr(III) concentrations. Among the RGB channels, the red intensity exhibited the most significant and consistent change with concentration and was therefore selected as the primary parameter for calibration and quantitative estimation.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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To improve measurement reliability, multiple readings were obtained for each sample and averaged. These RGB values formed the basis for subsequent MATLAB analysis and calibration curve development.

5.2 MATLAB Processing

MATLAB was utilized for processing, analyzing, and visualizing the extracted RGB data. The RGB intensity values were imported into MATLAB and arranged as numerical datasets for further analysis.

Graphs were plotted to examine the relationship between Cr(III) concentration and RGB intensity. Typically, chromium concentration was represented on the x-axis, while the corresponding RGB intensity values were plotted on the y-axis. The resulting plots revealed a clear trend between concentration and color intensity.

Regression analysis was performed to establish a mathematical relationship between the measured RGB values and Cr(III) concentration. A linear regression model was employed within the selected concentration range, and the coefficient of determination (R^2) was calculated to evaluate the goodness of fit and accuracy of the model.

MATLAB was also used for data filtering, error analysis, and calibration curve generation. The developed calibration curve enabled the estimation of chromium concentrations in unknown samples by comparing their RGB values with the standard reference data.

The results demonstrated that the smartphone-based sensing approach, combined with MATLAB analysis, provides an effective, reliable, and low-cost method for the quantitative detection of Cr(III) ions in water samples.

Samples		**Cr concentrations in ppm**			
		0.1	**0.2**	**0.3**	**0.4**
Sample 1 (Industrial Water)	Red	102.56	106.76	109.78	114.50
	Green	79.86	82.24	87.68	93.59
	Blue	65.90	75.87	83.49	91.13
Sample 2 (Filtered Water)	Red	99.89	10967	116.94	1120.29
	Green	78.94	85.56	92.73	97.02
	Blue	64.20	69.78	78.93	88.64
Sample 3 (Lake Water)	Red	113.78	117.67	120.89	127.56
	Green	83.45	87.68	90.13	95.87
	Blue	68.56	77.50	85.28	94.13
Sample 4 (River Water)	Red	91.65	111.43	117.84	123.27
	Green	82.53	87.65	90.61	93.40
	Blue	66.27	71.54	86.48	93.39
Sample 5 (Groundwater)	Red	100.76	107.65	112.64	115.84
	Green	67.38	74.35	88.32	92.86
	Blue	65.84	70.52	74.90	85.33

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Table 2: RGB values for different water samples

5.3 Calibration Curve

The calibration curve is a key component of the proposed sensing technique, as it establishes the relationship between known Cr(III) concentrations and their corresponding RGB intensity values. The curve was developed by plotting the RGB values obtained from standard chromium solutions against their respective concentrations.

A linear relationship was observed between chromium concentration and RGB intensity within the selected concentration range. This relationship enabled the development of a regression equation for quantitative analysis. The slope of the calibration curve represents the sensitivity of the sensing system, while the intercept corresponds to the baseline response.

The performance of the calibration model was evaluated using the coefficient of determination (R^2). An R^2 value close to unity indicated a strong correlation between concentration and RGB intensity, confirming the reliability and accuracy of the proposed method.

To improve precision and reproducibility, multiple measurements were taken for each concentration, and the average RGB values were used for calibration. The resulting calibration curve served as a reference for estimating the concentration of Cr(III) ions in unknown water samples.

Overall, the calibration curve validated the effectiveness of the smartphone-based sensing technique and demonstrated its capability for accurate, rapid, and quantitative determination of chromium ions in water.

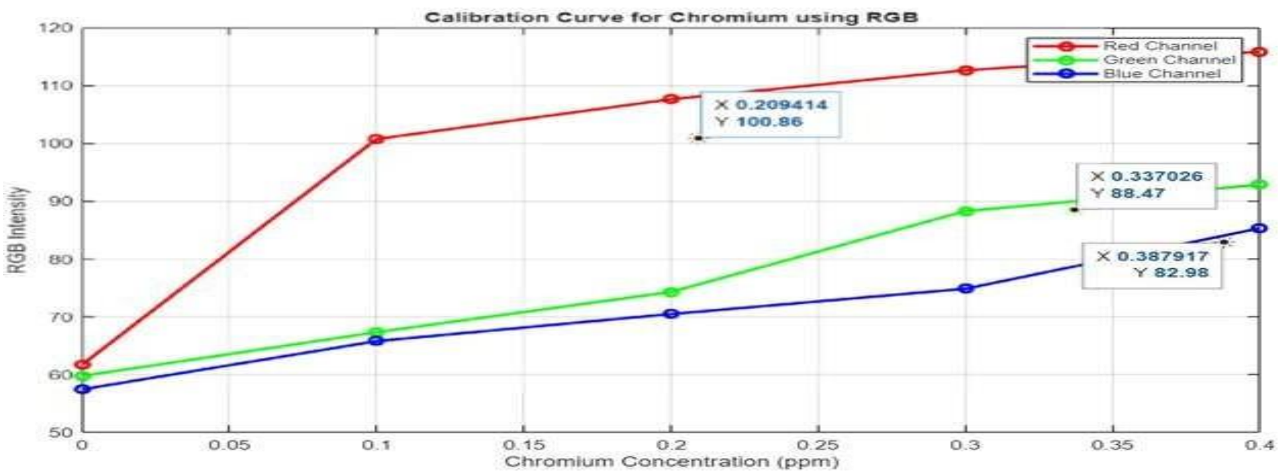

Fig.3. Industrial water

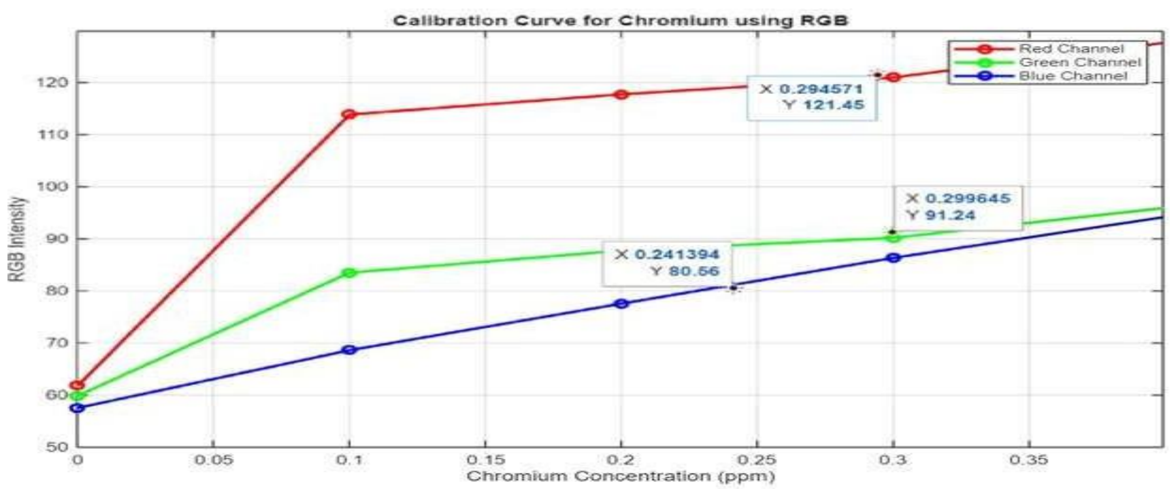

Fig.4. Filtered water

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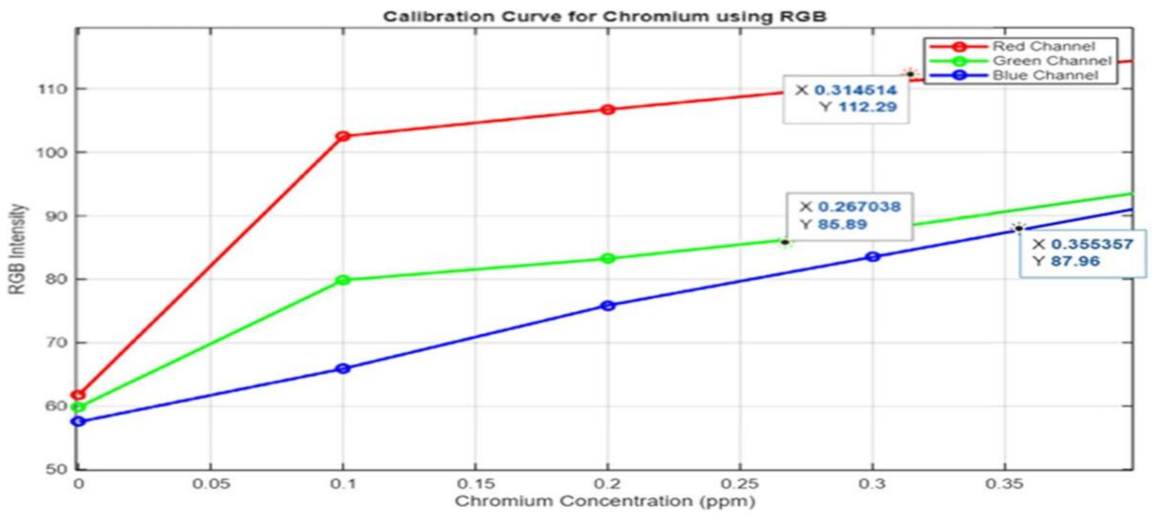

Fig.5. Lake water

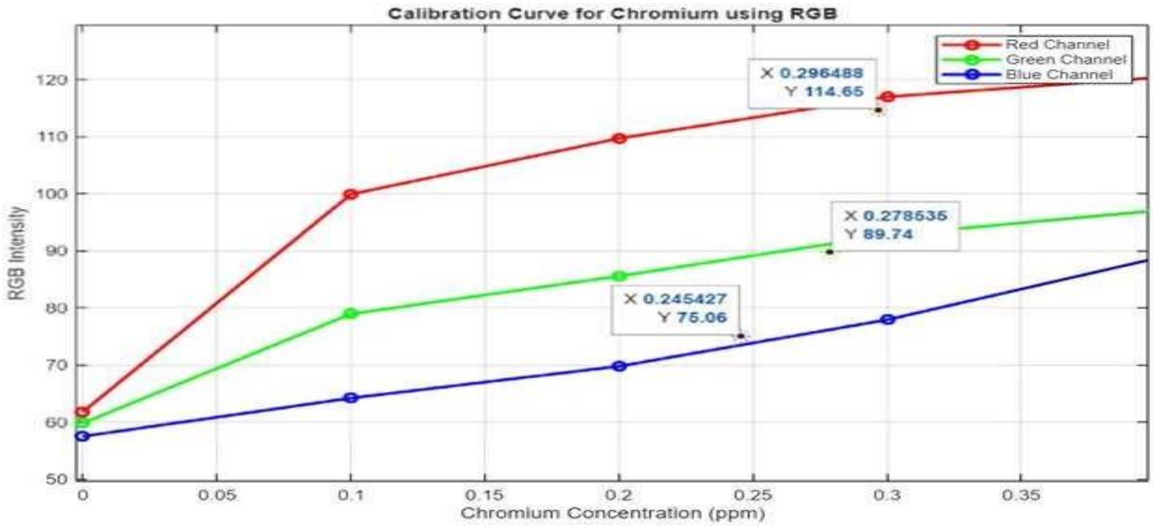

Fig.6. River water

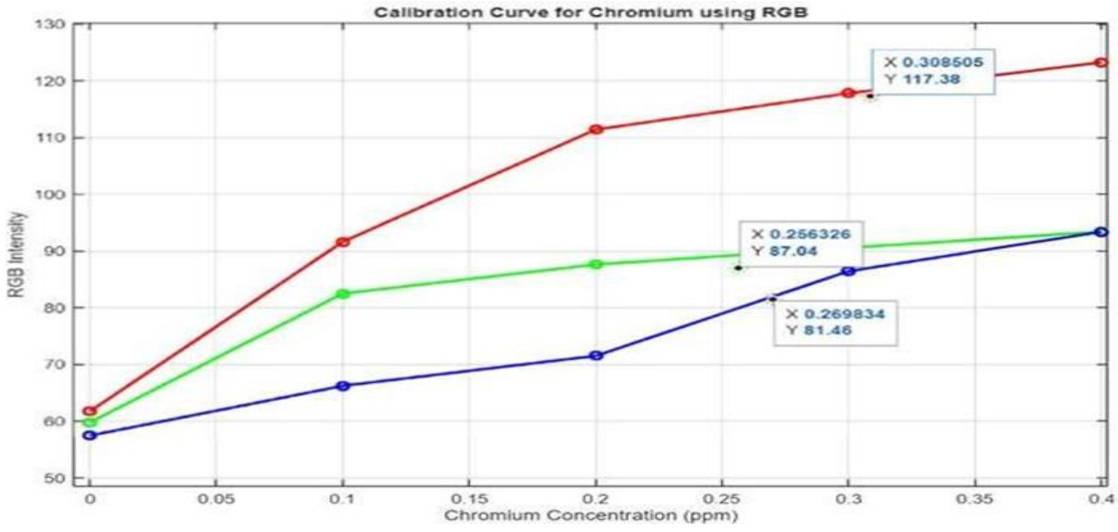

Fig.7. Ground water

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6. CONCLUSION

This study successfully developed a simple, cost-effective, and reliable method for the detection and estimation of Cr(III) ions in water using silver nanoparticles (AgNPs), smartphone-based imaging, and MATLAB analysis. The sensing mechanism was based on the colorimetric response of AgNPs, where interaction with Cr(III) ions produced measurable color changes due to alterations in their optical properties.

The color variations were captured using a smartphone camera under controlled conditions and analyzed through RGB image processing. A strong correlation was established between RGB intensity values and chromium concentration, enabling the development of an accurate calibration curve for quantitative analysis. Among the RGB channels, the most responsive channel exhibited good linearity and sensitivity, facilitating reliable estimation of chromium concentrations.

Experimental results demonstrated that the proposed method provides good accuracy, repeatability, and reproducibility within the investigated concentration range. The developed sensing system effectively quantified Cr(III) ions in water samples while requiring minimal instrumentation and operational expertise.

Compared with conventional analytical techniques such as Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma (ICP) methods, the proposed approach offers significant advantages, including low cost, portability, rapid analysis, and suitability for on-site applications. These features make it particularly valuable for environmental monitoring and water quality assessment in resource-limited regions.

In conclusion, the integration of silver nanoparticle-based sensing, smartphone imaging, and MATLAB-based RGB analysis presents a promising platform for real-time monitoring of chromium contamination in water. The methodology can be further extended and adapted for the detection of other heavy metals and environmental pollutants, contributing to sustainable water quality management and public health protection.

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