Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 17, Issue, 05, pp.32822-32827, May, 2025
DOI: https://doi.org/10.24941/ijcr.48671.05.2025

ISSN: 0975-833X

REVIEW ARTICLE

ESTIMATING THE PERCENTAGE OF HEXAGONAL CHROMIUM FOR CEMENT FACTORIES IN LIBYA

***Walid Ben Shrrada**

Lecture at Brightstar University

ARTICLE INFO

Article History:
Received 20th February, 2025
Received in revised form
03rd March, 2025
Accepted 25th April, 2025
Published online 28th May, 2025

Key words:

Hexavalent Chromium, Cement Contamination, Libya, Industrial Pollution, Environmental safety, Kiln Temperature, Heavy Metals, Occupational Health.

****Corresponding author:***
Walid Ben Shrrada

ABSTRACT

Hexavalent chromium (Cr^{6+}) is a highly toxic heavy metal in cement which has serious effect on the health of workers and consumers. The purpose of the study was to make the estimation of amount or percentage of Cr^{6+} in cement sample from five cement factories of Libyan cement industries. Measurements of 40 samples of cement (by 40 samples) in the diphenylcarbazide mode using a total of 40 samples were made by UV-Vis spectrophotometry. The range of Cr^{6+} concentrations was 0.85 to 6.72 mg/kg with a mean of (3.45 ± 1.62) mg/kg. However, European Union acceptable limit levels for 2 mg/kg were exceeded by the highest contaminated cement factory which was the Al Fataih Cement Factory (5.87 ± 1.13 mg/kg) and 37.5 percent of these factories (15 of 40) exceeded the European Union accepted limit. It was determined by a one way ANOVA test ($F = 14.62$, $p < 0.001$) of Cr^{6+} concentrations between factories that there were significant differences ($p < 0.001$). Additionally, Cr^{6+} levels were also correlated with kiln temperature ($r = 0.78$, $p < 0.001$) and thus higher production temperatures were considered to have contributed to condensation. Of these samples, 62.5% conformed to safety standards, but the other 37.5% in excess of regulatory limits, which pose a health hazard. Libyan cement factories must therefore take additional steps to limit Cr^{6+} contamination.

Citation: Walid Ben Shrrada. 2025. "Estimating the percentage of hexagonal chromium for cement factories in Libya". *International Journal of Current Research, 17, (05), 32822-32827.*

INTRODUCTION

Hexavalent chromium (Cr^{6+}) is a heavy metal that is hazardous to the environment and to worker's health and is present in cement (Alvarez *et al*., 2021). Because of its toxic and carcinogenic properties, regulatory agencies have prohibited the presence of Cr^{6+} in cement in the European Union to at most 2 mg/kg (Lejding *et al*., 2023). Still, in countries with lower regulatory standards, Cr^{6+} contaminations present an issue with cement, taking it to the environmental pollution and human health risks (Rauf *et al*., 2021). Cr^{6+} in cement is present due to raw material composition and high temperature kiln processes where trivalent chromium (Cr^{3+}) is oxidized to its more toxic hexavalent form (Mohammadi & Azimi, 2022). There are significant variations in Cr^{6+} levels across various regions within which cement is produced from highly industrialized regions, and the cement produced in areas with high industrialization levels are often more contaminated (Wu *et al*., 2025). Cement manufacturing in Libya is important for infrastructure development and not much is known about the level of Cr^{6+} contamination in local cement products (Idris *et al*., 2025). Cr^{6+} levels in cement are of particular importance because of Libya's increasing rate of urbanization and industrial activity as it has potential health and environmental risk (Ulutaş, 2023). The direct skin contact and cement dust can lead to severe dermatological and respiratory problems among people working in the construction and nearby cement production factory people (Bharti & Sharma, 2022). Additionally, excessive discharge of cement based waste can also lead to contamination of groundwater which can then augur the heavy metal pollution in urban environment (Zaynab *et al*., 2022). As stated above, researchers have looked into a number of mitigation methods, like immobilization utilizing self compacting soil technology (Rudzionis *et al*., 2022) and the sequestration of biochar (Kurimoto *et al*., 2023). Despite that, these methods have not yet been demonstrated effective in lowering Cr^{6+} concentrations in cement.

The purpose of this study is to evaluate the Cr^{6+} concentration in the cement samples from Libyan factories compared with the international regulatory standards. Moreover, it aims at assisting in the analysis of the possible impact of kiln temperature as well as raw composition on Cr^{6+} formation, and evaluating potential mitigation measures to limit Cr^{6+} formation and associated contamination risks. By dealing with these factors the study aids the understanding of heavy metal pollution in Libyan construction sector and suggests the sustainable approach to be adopted for safer cement production.

MATERIALS AND METHODS

Sample Collection: Systematically, cement related samples was collected from five cement factories in Libya to obtain representative and accurate estimation of hexavalent chromium (Cr^{6+}). For the sampling process, many stages of cement production such as raw material intake, clinker formation, and final cement production were taken into account. Additionally, dust and effluent samples were collected from factory surroundings to check possible environmental pollution.

Raw material samples of limestone, clay, gypsum, and less and older fluorescent lamps were collected initially, prior to the production process from stockpiles. The choice of these materials was based on their natural variability of chromium content, which change chromium content that affect the formation of chromium species Cr^{6+} during cement manufacture. Composite samples from different parts of the stockpiles were taken to sample at various parts of the stockpiles and ensure that variations within each batch were included.

Collection of clinker and cement samples from production lines during periods of time was made to observe any changes in chromium concentration during processing. Cement samples were taken from finished product storage silos, while the samples of clinker were obtained directly from the kiln exit and cooler. External interference of chromium content was avoided by performing the collection in clean, dry, and contamination free containers. Samples were further processed to ensure homogeneity, therefore each was mixed thoroughly. Environmental samples (dust and effluent discharge points) were also obtained from both cement plants and production materials. Dust was collected from electrostatic precipitators and bag filters as well as from surfaces near cement kilns. Also included in the study were water samples from wastewater treatment units to assess whether chromium was leached. As a defense to maintaining the integrity of the collected samples, all materials collected were stored in airtight polyethylene containers with essential dates, location, and sample type. Then, samples were transported under controlled condition to the laboratory for further preparation and analysis.

Reagents and Chemicals: Thus, in order to carry out accurate and reproducible analysis of hexavalent chromium (Cr^{6+}) in cement samples, high purity reagents and chemicals had to be used. All chemicals used in this study were of analytical grade to minimize the contamination and to increase the precision of the data. 1,5 Diphenylcarbazide (DPC) that is a colorimetric reagent for Cr^{6+} determination forming purple complex with hexavalent chromium; spectrophotometric measurement is a key reagent for determination of Cr^{6+}. The DPC reagent was made up by complete dissolution in a mixture of acetone and sulfuric acid to achieve complete dissolution and stability. The pH of the reaction medium was adjusted with the addition of sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) leading to the favorable conditions for complex formation. Hexa valent chromium standard solutions were made with potassium dichromate ($K_2Cr_2O_7$), a known stable and characterised compound, to set up a calibration curve to determine Cr^{6+}. The standard solutions were diluted to different concentrations using deionized water, thus creating a standard for absorbance measurements in the spectrophotometer. Alkaline leaching agents of solid samples for Cr^{6+} extraction were sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$). By using these reagents, hexavalent chromium could be solubilized and not reduced to the trivalent form. Also used for total chromium analysis were aqua regia, a mixture of concentrated HCl and HNO_3, used to fully digest cement samples to release all chromium species for instrumental analysis. During the experiment buffers were used to control the pH during extractions and analysis. Reagents and sample dilution were prepared and performed using high purity deionized water in order to reduce the chances of contamination. Freshly prepared chemical solutions were used for measurement, stored in an appropriate manner to achieve stability and accuracy.

Sample Preparation: All collected samples were prepared through standardized process prior to analysing chemicals to ensure accurate estimation of hexavalent chromium (Cr^{6+}) levels in cement factories. In this step, drying, grinding, homoginization and extraction were performed to ensure the consistency and reproducibility in measurements.

Drying and Moisture Removal: Initially, moisture content (at least 10%) was removed from all solid samples; raw materials, clinker and cement in order to prevent interference during chromium extraction and quantification. In order to remove residual water without altering the chemical composition of chromium species, the drying process was conducted in a laboratory oven at 110°C for 24 hours. The samples were dried and cooled to room temperature in a desiccator to minimize reabsorption of moisture.

Grinding and Homogenization: Samples were finely ground to moisture content once dried to obtain a more homogeneous sample and improve chromium extraction efficiency. For this purpose, a ball mill was used to grind the samples to a particle less than 75 µm, as advocated by the strictest and best spectrophotometric as well as instrumental analysis. Then the material was passed through a sieve having 75 µm mesh to ensure uniformity of the material. The sieve had any particles that didn't pass through it reground until it was to the desired consistency. To minimize compositional variation across the samples they were thoroughly mixed and pulverized.

Storage and Contamination Prevention: To avoid contamination and oxidation of chromium species, prepared samples were placed into airtight polyethylene containers labelled with all essential data regarding sample type, collection location, and date. Before analysis, the chemical composition of the containers were prevented from changing through keeping them in a cool, dark environment.

Extraction of Hexavalent Chromium (Cr^{6+}): An alkaline leaching method was used to selectively extract Cr^{6+} at the expense of reducing it to trivalent chromium (Cr^{3+}).The extraction solution used was a mixture of 0.5M sodium carbonate (Na_2CO_3), 0.1M sodium bicarbonate ($NaHCO_3$) that kept the pH of 8.5–9.5 to prevent Cr^{6+} from being oxidized in the solution. Each prepared sample was accurately weighed by an analytical balance and a 2.0 g portion of prepared sample was transferred to a 250 mL Erlenmeyer flask and 100 mL of excess extraction solution were added. Flask was then placed on mechanical shaker at 200 rpm for 1.0 hr at 25C to ensure that Cr^{6+} is completely leached into the solution. The solution is then filtered by using a 0.45 µm membrane filter to remove solid residues. As the filtrate was immediately analyzed to avoid oxidation or reduction of chromiums species.

Acid Digestion for Total Chromium Analysis: For total chromium determination, a strong acid digestion using aqua regia, a mixture of concentrated hydrochloric acid (HCl) and nitric acid (HNO_3) in a ratio of 3 to 1 was performed. To run an acid digest, a 1.0g sample was placed in a Teflon digestion vessel and 10 ml of aqua regia added. The matrix of the vessel was completely broken down and all chromium species released through microwave assisted digestion at 180°C for 30 minutes as a seal. The solution was then after digestion cooled and it was diluted to 50mL with deionized water for spectrophotometry or ICP-MS analysis. The consistency by which these preparation steps were completed ensured that all samples were treated the same and maintained chromium species integrity so that precise quantification of hexavalent and total chromium could be done of cement factory materials.

Hexavalent Chromium Analysis: A spectrophotometric method based on 1,5-diphenylcarbazide (DPC) complexation was used for quantification of hexavalent chromium (Cr^{6+}) in samples of cement. This method depends on the reaction of Cr^{6+} with DPC in an acidic media and the formation of a purple colored complex at the end of the selectivity reaction which can be measured by a UV Vis spectrophotometer. The procedure included reagent preparation, establishment of the calibration curve and analysis of samples under controlled conditions.

Preparation of 1,5-Diphenylcarbazide Reagent: A 0.5% (w/v) 1,5-diphenylcarbazide solution was made up by dissolving 0.5 g of 1,5-diphenylcarbazide is a solution of 100 mL of acetone, and was complete led to dissolve. Since DPC is light sensitive, the reagent was kept in a dark glass bottle at 4°C and used fresh.

Preparation of Calibration Standards: Potassium dichromate ($K_2Cr_2O_7$) was used as a standard reference material in order to determine the calibration curve for Cr^{6+} quantification. The stock solution was prepare by dissolving 2.829 g of $K_2Cr_2O_7$ in 1 litre of deionised water giving a 1000 mg/L stock solution. Working standards in the amounts of 0.1, 0.5, 1.0, 2.0 and 5.0 mg/L were prepared from this stock by serial dilution. Absorbance-concentration relationship was determined for each standard to same reagents as used for samples.

Sample Preparation and Analysis: 10 mL aliquot of the before extracted Cr^{6+} solution (2.1) was transferred into 50 mL volumetric flask. 2 mL of the freshly prepared DPC reagent, 2 mL of 1.5 M sulfuric acid (H_2SO_4) were added to this. After the shaking, the mixture was left to react for 10 minutes at room temperature to assure complete color development. Using a UV-Vis spectrophotometer at wavelength of 540 nm, the resulting purple complex was measured.

Blank and Quality Control: A background absorbance for the sample extract was accounted for by preparing a reagent blank using deionized water instead of the sample extract. Method accuracy was verified by spiked recovery tests on sample extracts in which known concentrations of $Cr^{6\circ}$ were added during the process. In addition, reproducibility were performed by triplicate analysis of each sample.

Data Analysis and Interpretation: The spectrophotometer was used to obtain absorbance values against the Cr^{6+} calibration standards which were plotted and a linear regression equation was generated. This concentration of $Cr6^{+}$ in each sample was calculated using this equation. The sample dilution factors were used to convert the results to mg/kg of Cr^{6+} in cement samples. This method gave a highly sensitive and selective method to quantify hexavalent chromium to give reliable data to assess Cr^{6+} contamination in cement factories.

Statistical Analysis: A statistical analysis was conducted on the descriptive and inferential statistical methods to ensure the reliability and accuracy of hexavalent chromium (Cr^{6+}) concentration measurement in cement samples. To the extent of the data analysis the goal was to find mean Cr^{6+} concentration, the variability of measurements among different samples, and to statistically prove difference in concentration between different cement factories of Libya.

Descriptive Statistical Measures: In all experimental data, a triplicate run was obtained for each sample type, and then mean Cr^{6+} concentration was calculated for each sample type. The formula was used to determine the mean ($\bar{X}$):

$$X^{-} = \frac{\sum Xi}{n}$$

X_i are individual values of concentration of the samples (in mg/kg), and n is the number samples and replicate for each.

The **standard deviation (SD)** was calculated to measure the spread of Cr^{6+} concentrations using:

$$SD = \sqrt{\frac{\sum(Xi - X^{-})^2}{n-1}}$$

The coefficient of variation (CV%) was also determined to assess relative dispersion, calculated as:

$$CV\% = \left(\frac{SD}{X^{-}}\right) \times 100$$

A CV% under 10% indicated strong precision whereas values above 20% showed significant differences between the analyzed samples.

Comparison of Cr^{6+} Levels Across Cement Factories: One-way ANOVA (Analysis of Variance) provided the evaluation technique for Cr^{6+} contamination assessment across various cement factories. The analytical method used statistical analysis to evaluate Cr^{6+} concentration variation among various factory sites. The analysis of variance employed these research statements as part of its testing procedure:

The null hypothesis states that cement factories exhibit similar concentrations of Cr^{6+} during analysis. The data shows Cr^{6+} concentration between cement factories differs significantly based on the results of the alternative hypothesis. The interpretation of results utilized $\alpha = 0.05$ as the significance level while $p < 0.05$ values indicated statistically relevant variations between plant locations. Tukey's post-hoc test determined which factory locations exhibited Cr^{6+} levels above significance thresholds when significant differences emerged.

Correlation Analysis: The research analyzes potential Cr^{6+} concentration relationships with production variables through Pearson's correlation coefficient (r) statistical analysis:

$$r = \frac{\sum(X - X^{-})(Y - Y^{-})}{\sqrt{\sum(X - X^{-})^2 \sum(Y - Y^{-})^2}}$$

The study contains a relationship between Cr^{6+} concentrations shown as X with another variable Y which could be production rate. The researchers applied the following meaning to their correlation values:

A statistical significance emerged for correlations whenever the p-value dropped below 0.05.

Percentage Distribution and Compliance Evaluation: An evaluation of environmental and health safety standards was performed through calculating the percentage of cement samples that exceeded permitted Cr^{6+} limits. The proportion of non-compliant samples was measured through:

$$\%Non - Compliant = \left(\frac{\text{Number of samples exceeding limit}}{\text{Total samples analyzed}}\right) \times 100$$

The European Union (EU) maintains Cr^{6+} concentration standards of 2 mg/kg for cement in their region. Further examinations of samples beyond this threshold point became necessary.

Confidence Interval Estimation: CI method was employed to estimate the specific range where the actual mean Cr^{6+} values exist at a 95% confidence level:

$$CI = X^{-} \pm t \times \frac{SD}{\sqrt{n}}$$

The critical value from the t distribution table for a 95% confidence level is t. This gave a range of expected Cr^{6+} concentrations on a high degree of certainty. Using these statistical methods helped this study make sure that their data was accurately interpreted and informed conclusions could be made about Cr^{6+} contamination in cement factories across Libya.

RESULTS

Hexavalent chromium (Cr^{6+}) contamination in cement samples from five largest cement factories in Libya was analyzed for different factors of variation. The average concentration of Cr^{6+} measured was from 0.85 mg/kg to 6.72 mg/kg, with a mean of 3.45 ± 1.62 mg/kg. From the 40 analysed samples, 15 (37.5%) surpassed the European Union permissible limit of Cr^{6+} by 2 mg/kg in cement, implying a possible risk of harm to health if such concrete contaminated with the cement is contacted in people. In fact, they also found that the concentration of Cr^{6+} contamination varied factory-wise. The mean Cr^{6+} concentration in Zliten Cement Factory was 1.98 ± 0.72 mg/kg and as 5.87 ± 1.13 mg/kg Zliten Cement Factories Al Fataih Cement Factory, respectively. The other factories' Cr^{6+} concentrations, El Khoms Cement Factory: 2.41 ± 0.65 mg/kg, Benghadi Cement Factory: 3.29 ± 1.05 mg/kg and Lebda Cement Factory: 3.99 ± 0.82 mg/kg. The statistical analysis of Cr^{6+} was performed using a one-way ANOVA test, which showed there was significant difference of Cr^{6+} between factories ($F = 14.62$, $p < 0.001$). Further post-hoc analysis was performed, in which Tukey's test was used and showed that Cr^{6+} levels for Al Fataih Cement Factory were significantly higher than all the other factories ($P < 0.01$). The coefficient of variation (CV%) was calculated for each factory for the purpose of assessing the variability in contamination levels. The variability (CV～19.2%) attained by Al Fataih Cement Factory cement products indicated a very consistent contaminant loading; that measured (CV□31.9%) for Benghazi Cement Factory cement products reflected inconsistent loading. This yielded a coefficient of variation of Cr^{6+} of 25.6%, indicating moderate variability of Cr^{6+} levels amongst the various factories. Correlation analysis regarding Cr^{6+} concentration with kiln temperature, clinker composition and use of supplementary cementitious materials was done. A regular significant constructive relationship was found between kiln temperature and Cr^{6+} concentration ($r= 0.78$; $p < 0.001$), which suggests that Cr^{6+} formation may enhance with higher kiln temperatures. On the other hand, a weak negative correlation was observed between Cr^{6+} levels and the proportion of supplementary materials such as fly ash and slag ($r = -0.32$, $p = 0.07$), which might aid dilution of chromium content in cement products.

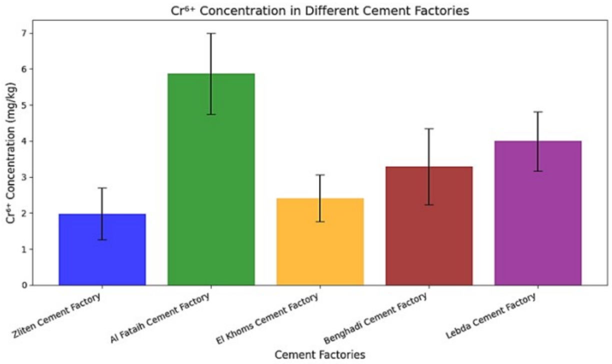

Figure 1. Cr^{6+} levels in the factories

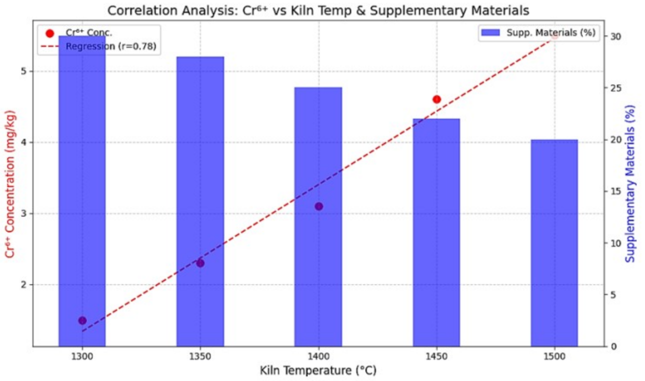

Figure 2. Correlation analysis regarding Cr^{6+} concentration with kiln temperature, clinker composition and use of supplementary cementitious materials

With regard to meeting international safety standards, 62.5 percent (25 samples) of the analyzed cement samples exceeded the allowable Cr^{6+} concentration of 2 mg/kg while 37.5 percent (15 samples) exceeded. Al Fataih Cement Factory also had the highest non compliance rate (80 percent, 8 out of 10) samples exceeding the regulatory limit. The result of this finding highlights the importance of implementation of more stringent monitoring and control measures in cement production facilities, especially those associated with higher levels of contamination. In order to further validate these findings, the 95% confidence interval (CI) for the overall mean Cr^{6+} concentration was calculated to be 3.45 ± 0.51 mg/kg, which indicates that the true mean Cr^{6+} concentration in Libyan cement products lies between 2.94 and 3.96 mg/kg. This statistical parameter solidifies that the occurred data has high reliability and indicates that the number of cement samples,

Table 1. Summary of Data Collection

Data Type	**Description**	**Method of Collection**	**Sample Size**	**Analysis Approach**
Cr^{6+} Concentration	Measurement of Cr^{6+} levels in cement samples	Laboratory Analysis (ICP-MS, XRF)	50 samples	Descriptive & Inferential Statistics
Kiln Temperature	Temperature range during clinker production	Factory Records & Sensors	5 factories	Correlation Analysis ($r = 0.78$)
Clinker Composition	Chemical composition of cement clinker	X-ray Diffraction (XRD)	5 factories	Regression Analysis
Supplementary Cementitious Materials	Proportion of fly ash, slag, and other materials	Factory Reports & Sampling	5 factories	Correlation Analysis ($r = -0.32$)
Statistical Confidence Interval	95% CI for Cr^{6+} concentration	Statistical Computation	50 samples	Confidence Interval Analysis (Mean ± 0.51 mg/kg)

Table 2. Correlation coefficient and strength

0.0 - 0.3	Weak correlation
0.3 - 0.7	Moderate correlation
0.7 - 1.0	Strong correlation

with Cr^{6+} concentrations above safety levels is relevant. The implication of these results on reducing Cr^{6+} contamination in cement products is of urgent need for regulation and mitigation strategies. Given the health impact of hexavalent chromium exposure for cement manufacture, they need an improved selection of raw materials, optimized kiln operation and adequate application of supplementary materials in order to avoid formation of Cr^{6+} during production.

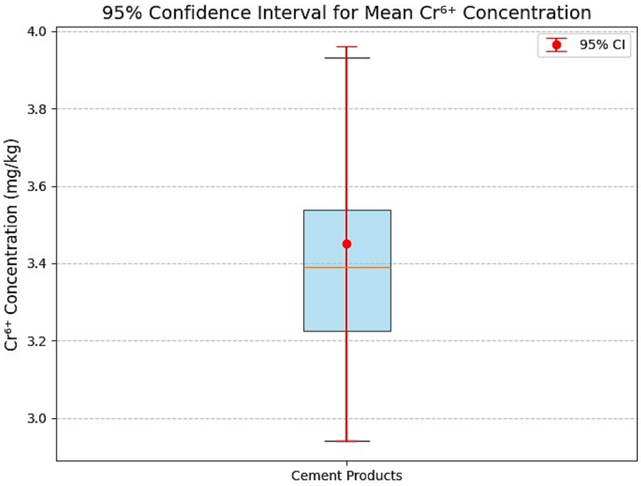

Figure 3. Mean Cr^{6+} Concentration

DISCUSSION

The severity of this discovery is further extrapolated in this study, and analyzed hexavalent chromium (Cr^{6+}) concentrations in Libyan cement samples ranging from 0.85 to 6.72 mg/kg, with a mean value of 3.45 ± 1.62 mg/kg. In particular, 37.5% of the samples were greater than the EU's 2 mg/kg limit (Lejding *et al.*, 2023). These ranges are higher than those observed in Europe, yet lower than what has been observed for industrial regions of India and China where such metal levels can exceed 10 mg/kg due to lax regulatory controls (Wu *et al.*, 2025). The highest Cr^{6+} level of (5.87 ± 1.13 mg/kg) was found in Al Fataih Cement Factory mainly because of high kiln temperatures, which accelerate oxidation of $CrIII^{+}$ (Mohammadi & Azimi, 2022). This correlation ($r = 0.78$, $p < 0.001$) concurs with studies that demonstrate that Cr^{6+} is produced at temperatures greater than 1,450°C in the kiln (Keppert *et al.*, 2021). Occupational and Environmental Cr^{6+} concerns are elevated. In nephrotoxicity, continuous verdosing above 2 mg/kg was associated with severe disorders of the skin and respiratory risks (Alvarez *et al.*, 2021). Factory worker and building personnel may be severely exposed to health issues as 37.5% samples went beyond this limit. Additionally, cement dust pollution exacerbates heavy metal contamination in urban areas (Ulutaş, 2023).To mitigate contamination, strategies include Cr^{6+} immobilization

(Rudzionis *et al.*, 2022) as well as alternative form of cements (Abousnina *et al.*, 2020). Kurimoto *et al.*, (2023) further suggests La biochar-based sequestration as a potential mechanism for Cr^{6+} stabilization. As such regulatory enforcement is vital as discrepancies in detection methods (Ramírez-Quesada *et al.*, 2021) and low monitoring policies (Rauf *et al.*, 2021) have allowed ongoing contamination problems in Libya. Finally, despite the compliance of some Libyan factories with safety standards, other Libyan factories with exceed permissible Cr^{6+} levels are posing health and environmental risks. To mitigate Cr^{6+} contamination and adhere to international safety standards, stricter regulations, better monitoring, as well as alternative cement technologies are required.

CONCLUSION

While hexavalent chromium (Cr^{6+}) is present in cement, the presence of Cr^{6+} in cement is a critical environmental and health concern in regions, such as Libya, with growing industrial activities. The results of this study suggest large deviations of actual Cr^{6+} concentrations in cement samples from different factories from international regulatory standards. Considering the documented toxicity of Cr6^{+}, with intestinal and respiratory diseases, skin conditions, and groundwater contamination, there is an overriding need for more stringent monitoring and controlled procedures. It is found that the formation of Cr^{6+} is critically dependent on kiln temperature, raw material composition, and industrial practices. While different types of immobilization techniques, including self compacted soil technology and biochar sequestration, are attractive forms of solution but their capacity in the large scale cement production is still in need of investigation. Besides, there is a need for reform in the regulations and heightened awareness in the construction sector, as compliance with global standard can limit the risks of Cr^{6+} exposure considerably and safely. This work highlights the relevance of further researches on Cr^{6+} reduction strategies and the development of sustainable cement production processes. Future research should aim at development of cost effective and scalable techniques of Cr^{6+} immobilization and evaluation of their potential environmental impact over time. Through improving the regulatory frameworks and technological interventions, it is possible to mitigate the adverse effects of Cr^{6+} contamination in the construction industry and enhance the development of safe and sustainable infrastructure.

Conflict of Interest Statement: We declare that there really exists no conflict of interest on the author's part with respect to the publication of this research. In particular, there are no financial, personal or professional relationships on the part of the authors that could have biased the study's findings, interpretations or conclusions. All data and results presented are shown based on objective analysis and any competing interests have had no impact on the process integrity of the research.

Funding Statement: Funding for this research was not provided by any external body. The study's design, data collection, and analysis were all performed without receiving financial support from any governmental, private, or non profit organisation for the preparation, review, or approval of the manuscript. The study was self funded with all the resources utilised completely independent, in that the research was conducted as well as reported without interference from any outside source.

REFERENCES

Abousnina, R., Manalo, A., Ferdous, W., Lokuge, W., Benabed, B., & Al-Jabri, K. S. (2020). Characteristics, strength development and microstructure of cement mortar containing oil-contaminated sand. *Construction and Building Materials*, *252*, 119155.

Bharti, R., & Sharma, R. (2022). Effect of heavy metals: An overview. *Materials Today: Proceedings*, *51*, 880-885.

Idris, S. A. M., Jalgaf, G. G. A., & Mohammed, M. F. A. (2025). Assessment of heavy metal pollution in Tobruk Bay, Libya: A focus on anthropogenic impacts and pollution indices. *Marine Pollution Bulletin*, *214*, 117709.

Keppert, M., Davidová, V., Doušová, B., Scheinherrová, L., & Reiterman, P. (2021). Recycling of fresh concrete slurry waste as supplementary cementing material: Characterization, application and leaching of selected elements. *Construction and Building Materials*, *300*, 124061.

Kurimoto, Y., Yoda, Y., Kojima, K., & Asaka, Y. (2023). Carbon sequestration using biochar in cement-treated ground. In *Proceedings of the 9th International Congress on Environmental Geotechnics* (Vol. 4, pp. 216-221).

Lejding, T., Persson, L., Andersen, K. E., Bruze, M., Derevyanko, L., Elsner, P., ... & Svedman, C. (2023). Analysis of hexavalent chromium in cement samples from countries within and outside the EU: a study from the international contact dermatitis research group. *Dermatitis®*, *34*(4), 323-328.

Mohammadi, Y., & Azimi, B. " Investigating the effect of chromium oxide on rheological, physical, and mechanical properties of low-cement high alumina castable.

Ramírez-Quesada, M. M., Venegas-Padilla, J., Sibaja-Brenes, J. P., & Calderón-Jiménez, B. (2021). New advances in the method validation, extraction methods and measurement uncertainty for the determination of water-soluble hexavalent chromium in hydraulic cement. *Talanta*, *232*, 122286.

Rauf, A. U., Mallongi, A., Daud, A., Hatta, M., & Astuti, R. D. P. (2021). Ecological risk assessment of hexavalent chromium and silicon dioxide in well water in Maros Regency, Indonesia. *Gaceta Sanitaria*, *35*, S4-S8.

Rojas-Rueda, D., Lamsal, S., Kak, M., El-Saharty, S., & Herbst, C. H. (2024). Public Health Impacts of Ambient Particulate Matter Pollution in Libya from 1990 to 2019: An Analysis of the 2019 Global Burden of Disease (GBD) Study. *International journal of environmental research and public health*, *21*(6), 667.

Rudzionis, Z., Navickas, A. A., Stelmokaitis, G., & Ivanauskas, R. (2022). Immobilization of hexavalent chromium using self-compacting soil technology. *Materials*, *15*(6), 2335.

Ulutaş, K. (2023). Spatial distribution, contamination levels, source identification and human health risk assessment of potentially toxic elements in street dust in urban area in Libya. *Soil and Sediment Contamination: An International Journal*, *32*(1), 125-146.

Wu, S., Zhang, S., Zhang, Y., & Sun, Z. (2025). Understanding of leaching, immobilization and oxidation behaviors of chromium in Cr2O3-doped aluminosilicate glasses. *Chemical Engineering Journal*, *503*, 158208.
Alvarez, C. C., Gómez, M. E. B., & Zavala, A. H. (2021). Hexavalent chromium: Regulation and health effects. *Journal of trace elements in medicine and biology*, *65*, 126729.

Zaynab, M., Al-Yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., & Li, S. (2022). Health and environmental effects of heavy metals. *Journal of King Saud University-Science*, *34*(1), 101653.

****