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ASSESSMENT OF CHEMICAL RISKS ON THE HEALTH OF COPPERSMITHS AND ON THE ENVIRONMENT: CASE OF BARDO IN CONSTANTINE (ALGERIA)

Abstract: Certain traditional industries and crafts are major sources of environmental pollution and health risks. Copperware craft is one of those activities that exposes artisans to numerous health risks, including chemical hazards. The current study aims to identify the risks associated with the workshops of the Bardo site in Constantine, Algeria, and to analyze the concentration of heavy metals in samples of water used for the treatment of copper in order to evaluate their environmental impact. The methodology included interviews with 15 coppersmiths, as well as a chemical analysis of three water samples from the workshops. The analysis measured the pH level, chemical oxygen demand (COD), total organic carbon (TOC), and turbidity. It also measured the concentration of heavy metals, such as copper, arsenic, zinc, lead, cadmium, and total chromium. The results revealed that 73% of artisans suffer from respiratory problems and allergies due to inadequate use of protective equipment. Analysis of the samples showed significant acidity ranging from 0.2 to 1.5, high COD values reaching 6,176 mg/L, and significant excesses from environmental standards for arsenic (0.1031 mg/L), cadmium (0.0075 mg/L), and total chromium (0.007 mg/L). As these polluted waters are discharged directly into the environment, they pose a danger to Oued Rhumel, located downstream from the workshops, where high concentrations of heavy metals such as copper (3125 mg/kg), zinc (1570 mg/kg), and cadmium (199.5 mg/kg) have been detected in the sediments. This craft presents a dual threat to both human health and the environment. Therefore, the study recommends strengthening safety measures, treating water before discharge, and opting for less hazardous alternatives.

Keywords: health risk, environmental risk, heavy metals, pollution, copperware craft, Constantine.

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Introduction

In the literature, a job that has resulted in permanent disability (Jounin, 2006) and causes physical injury, respiratory or muscular disorders, burns, and sometimes has caused death (Jounin, 2006) following exposure to harmful products, is considered a “high-risk occupation” (Hiscox, 2023), referring to a profession or activity that exposes individuals to dangers, difficulties, or potentially harmful situations (Hiscox, 2023).

Certain traditional industries and craft activities are a major source of environmental pollution and disease for populations. In many developing countries, where few rigorous environmental control mechanisms are in place, industrial facilities and craft workshops use chemicals rich in heavy metals such as lead, mercury, and cadmium in their manufacturing processes without complying with safety standards. The release of these metals into the soil and water systems leads to their bioaccumulation, posing a double risk to the environment and public health (Ayangbenro & Babalola, 2017). These practices can also help transform the attributes of the ecosystems in the long term (Nriagu & Pacyna, 1988). Several expert reports confirm these findings: Research conducted in Dakar on 21 foundries and 53 artisans attests that the foundry environment is dangerous and is characterized by spontaneous exposure to multiple chemical, physical, and mechanical occupational hazards. Workers are exposed to numerous nuisances and risks and suffer from illnesses related to their work. The study notes that chemical hazards related to silica and other non-metallic dusts and fumes, carbon monoxide and other chemical compounds, including decomposition products have affected employees in this industry, and that foundry workshops were responsible for neighborhood and air pollution (Dia, et al., 2017). Another study that looked at the health risks associated with working in a lead-acid battery manufacturing and recycling plant in eastern Algeria found that lead was the most prevalent element in the blood of workers (521.24 μg/L) compared to the control group (23.08 μg/L). Cadmium levels were significantly higher in the blood of exposed workers than in the control group (Bouchala, et al., 2023). Although the results of these researches confirm the harmful impact of heavy metals emitted by factories and workshops on both the health and the environment, they have addressed this issue in a one-dimensional manner. They have focused either on the occupational risks to which workers are exposed or on the environmental damage caused by these activities; without considering an integrated perspective linking these two aspects. Furthermore, researches specifically concerned with health risks and the assessment of environmental impacts related to traditional craft activities in Algeria remain limited.

Like so many other activities, copperware craft is associated with a multitude of risks, given its manual nature and high physical demand, as well as the use of traditional tools and hazardous materials that can threaten the health (injuries, burns, heavy metal poisoning, etc.) and the environment through the discharge of polluted water from polishing and nickel-plating processes. This research therefore proposes to adopt a multidisciplinary approach to study the impacts of this activity, known as “dinanderie,” on the health of artisans and the surrounding environment at one of the former copperware sites, “Bardo,” described as an artisan cluster in Constantine, Algeria.

Study area

Constantine is one of the oldest cities in Algeria. It is characterized by its strategic location at the crossroads of eastern Algerian cities and its exceptional geographical position on the rock bordered by Oued Rhumel. The city is known for having been home to many civilizations, each of which left its marks and traces, both tangible and intangible. Craftsmanship is one of the various activities that has been present since ancient times, making Constantine one of the metropolises that punctuate the production and exchange network of cultural industries (Mazri Benarioua, 2022).

Copperware represents the cultural identity of the city and is currently located in the Bardo district on the south side of Constantine's city center. The study was conducted in this district, which is characterized by a high concentration of traditional copperware workshops and is considered a cluster, compared to the 81 other workshops scattered across several locations in the city. The copperware site (Bardo) is located on the main Rahmani Achour road, bordered by European-style buildings; except on its western side where it is bordered by the Bardo urban park and Oued Rhumel (approximately 500 m away) (Fig. 1).

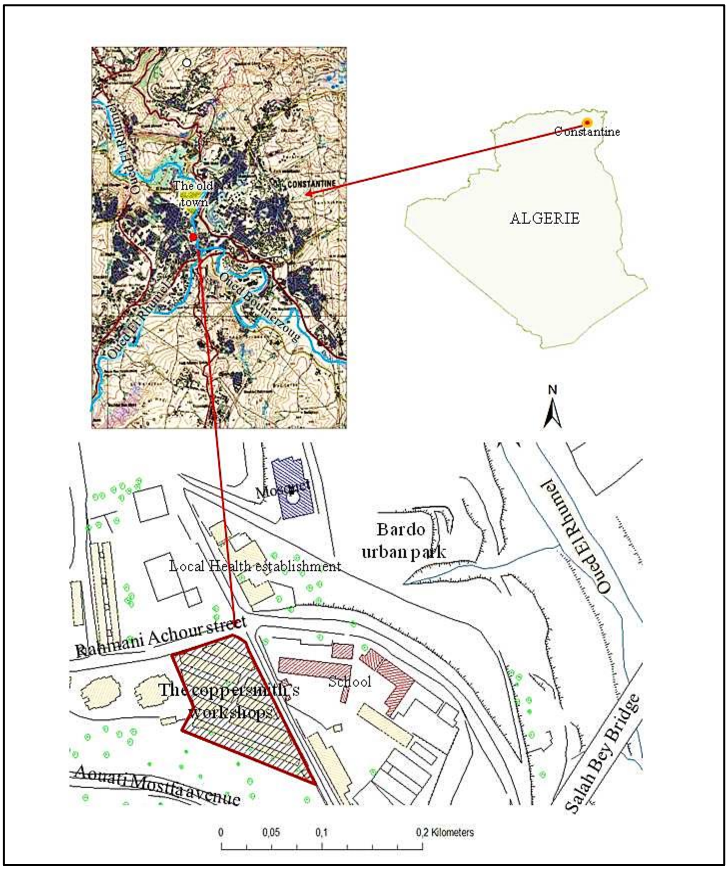

Fig. 1. Location of the Bardo coppersmiths' site in Constantine, Algeria[2]

[2] This figure shows the location of the Bardo coppersmiths' workshops in the city of Constantine, located in northeastern Algeria. The inset map (top right) shows the position of Constantine within the national territory of Algeria. The upper-left map situates the study area within the broader urban structure of Constantine, highlighting the old town and the surrounding districts. The detailed map (bottom) precisely delineates the copper workshop area in Bardo, outlined in red, along Rahmani Achour Street and near Aouati Mostafa Avenue. The site is located in close proximity to key urban elements, including a local health establishment, a mosque, a school, Bardo Urban Park, Oued Rhumel, and Salah Bey Bridge.

There are 74 copperware workshops spread across nine buildings on the ground floor. All stages of copper craft production take place on these premises, including cutting copper (bronze or brass) pieces, drawing and engraving, firing, cleaning, polishing, and marketing the items. Each stage requires specific tools, techniques, and processes.

The artisans have been practicing this craft for a long time, which reflects skills passed down from generation to generation (Rezki & Abidi, 2024). To this end, they preserve the ancient heritage and develop new creations through their skill, patience, and experience.

Aims

This study aims to assess the current situation in the coppersmiths' neighborhood, identify chemical risks; understand their origins, and determine the extent of these threats, which have developed over the years as a result of the coppersmiths' work. It also aims to determine the concentrations of heavy metals in the rinsing basins for copper items by analyzing water samples in the laboratory and to identify any contamination of neighboring ecosystems. All this aims at providing scientific data to support preventive actions, improve health conditions at work, and protect the environment.

Material and Methods

Copper objects contain a small percentage of impurities; the main ones being arsenic, antimony, lead, iron, zinc, tin, etc. The presence of these impurities (Gharib & Maher, 2018) can lead to occupational hazards impacting the health and well-being of coppersmiths -who work long hours in poorly lit, poorly ventilated, and noisy workshops- such as persistent respiratory problems, skin irritation, and muscle pain due to poor posture, etc. These impurities cause water pollution; particularly if the toxic substances are not neutralized at source or are not brought down to acceptable levels before being released into the environment. This pollution is considered to be an alteration in its quality and nature that makes its use dangerous and/or disrupts the aquatic ecosystem (Arris, 2008). It can come from various sources such as human activity, industry, agriculture, and domestic and industrial waste dumps. This can lead to disease, the rapid death of various organisms (Arris, 2008), and have an impact on food security and sustainable development. Some of the heavy metals used in copper craftsmanship, such as mercury, copper, cadmium, etc., are a cause for concern when involved in water pollution (Arris, 2008); especially if they have not been treated effectively before being discharged into the environment.

To achieve the objectives of this research, we conducted our investigation in two complementary stages, adopting a mixed methodological approach combining field interviews and laboratory chemical analyses.

This methodological choice aims to cross-reference socio-professional data, relating to working conditions with objective analytical data to assess the potential health and environmental impact of artisanal activities.

Qualitative survey of coppersmiths

This stage consisted of conducting a qualitative field survey on 15 coppersmiths in Bardo (representing 20.27% of the total number of workshops) using semi-structured interviews with the artisans who agreed to participate in our work. The aim was to understand their working conditions, identify the chemical risks to which they are exposed, and understand the impact of these practices on their health. This survey took place in January 2022. The data collected was used to describe the socio-professional profile, professional experience, and duration of daily exposure to artisanal processes.

According to our sample, 73.3% of our respondents are aged between 18 and 60 years old, and 26.7% are over 60 years old, which is a group that combines professional experience and ancestral know-how. The majority of interviewees (40%) had an average level of education, followed by the category of those with a primary school education (26.7%), then those with secondary school education (20%), and finally, the interviewees who had no education (13.3%). The latter acquired their skills through observation, practice, and intergenerational transmission of know-how. 73.3% of our interviewees have been practicing this profession for more than two decades, while 13.3% constitute a part of the new generation, having recently been introduced to copperware making -less than five years ago- and working under the supervision of qualified artisans. Another category, representing 13.4%, had between 6 and 20 years of experience. This category consists of artisans who practice their craft part-time or retirees who devote themselves fully to craftsmanship.

Copperware craft is an activity that requires effort, patience, and perseverance over many hours and days of work. The majority of our respondents (73.3%) work between 5 and 8 hours a day; while 20% work more than 8 hours to complete accumulated tasks or fulfill customer orders. 6.7% are artisans who work less than 5 hours a day. This category of artisans generally includes people who sell copper objects. Working hours are adapted according to the intensity of demand or the nature of the tasks reflecting the characteristic of professional autonomy; where the artisan manages the pace of their work and adjusts it according to their priorities (Sennett, 2008).

It should be noted that although the size of the sample (17 interviews) is relatively small and may constitute a methodological limitation that could affect the statistical representativeness of the results, this survey provides a relevant exploratory basis in a poorly documented artisanal context; where similar practices have been observed and adopted in most workshops in Constantine.

Sampling of wastewater generated by the copperware activity

This stage focuses on an experimental analysis of wastewater generated by workshops, used in the manufacture of copper items. To this end, in February 2025, we established preliminary coordination with five artisans, working in the Bardo district, who authorized the collection of wastewater samples from the polishing and cleaning stage (Fig. 2) - which consumes the most chemicals, solvents, and acids, and may also contain heavy metals. However, during collection, only three artisans agreed to have water samples taken. This limited number of samples ($n = 3$) is considered an exploratory investigation in an uncontrolled setting.

Fig. 2. Cleaning phase of a large handcrafted copper tray in a traditional workshop[3]

Wastewater samples were collected from these three traditional copperware workshops, where copper and brass alloys are shaped, polished, and chemically treated. The industrial processes include cutting, mechanical polishing, acid pickling (HCl and/or H_2SO_4), and surface finishing.

Composite samples were collected at the final discharge point prior to any treatment unit. Sampling was performed in pre-cleaned polyethylene bottles (Fig. 3). Samples intended for metal analysis were acidified to pH < 2 using ultrapure nitric acid (HNO_3) to prevent metal precipitation and adsorption onto container walls. All samples were stored at 4 °C and analyzed within 24–48 h according to international standard procedures.

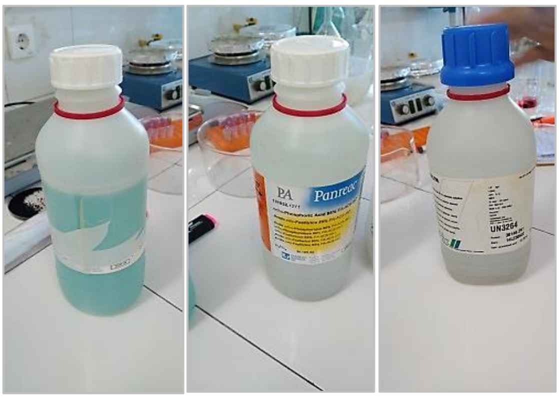

Fig. 3. Samples of water used in the treatment of copper articles[4]

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[3] The figure illustrates the manual cleaning and surface treatment of a large copper tray using water and chemical agents. This stage involves intensive washing and scrubbing to remove oxidation layers, polishing residues, and surface impurities. The process generates wastewater containing suspended solids, metal particles (e.g., Cu, Cr, Zn), and residual chemicals, which may contribute to environmental contamination if discharged without adequate treatment.

[4] These polyethylene bottles contain water samples collected from copperware workshops, intended for heavy metal analysis to assess contamination levels.

Selection of analytical parameters

The selection of analytical parameters was based on:

- the metallurgical nature of processed materials (Cu-based alloys),
- the chemical treatments applied during production, and
- national and international discharge regulations, including those adopted in Algeria and the environmental guidelines of the European Union.

Physicochemical Parameters

The general water quality parameters were determined according to the relevant ISO standards:

- pH is a critical parameter controlling metal solubility and speciation (International Organization for Standardization [ISO] 10523).
- Turbidity was determined using the nephelometric method (ISO 7027). This method estimates the presence of suspended particles that may adsorb or transport metal contaminants.

These parameters provide a general assessment of wastewater quality and its potential impact on receiving water bodies.

Organic Load

Although metal pollution is predominant in copperware effluents, organic contaminants may originate from lubricants and polishing agents.

-Chemical oxygen demand (COD) was analyzed using the dichromate method (ISO 6060). This parameter provides information on the total oxidizable organic load present in the effluent, particularly that originating from solvents, polishing agents, and degreasers used in workshops.

-Total organic carbon (TOC) was measured to quantify the dissolved and particulate organic fraction. The TOC analysis complements the organic load assessment and makes it possible to evaluate the potential impact on the receiving environment in the event of uncontrolled discharge.

These parameters were selected to evaluate the potential impact on biological wastewater treatment systems and oxygen depletion risks.

Heavy Metals

Given the composition of copper-based alloys and surface treatment processes, the following metals were quantified:

- Cadmium (Cd)
- Arsenic (As)
- Lead (Pb)
- Total Chromium (Cr)
- Nickel (Ni)
- Copper (Cu)

• Zinc (Zn)

Metal concentrations were determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) following ISO 11885. Heavy metals were prioritized due to their toxicity, persistence, and bioaccumulation potential in aquatic ecosystems (Fu & Wang, 2011; Tchounwou, et al., 2012).

Quality Assurance and Quality Control (QA/QC)

All analyses were conducted in triplicate. Calibration curves were prepared using certified standard solutions. Blanks and quality control samples were included in each analytical batch. The relative standard deviation (RSD) was maintained below 5% for physicochemical parameters and below 10% for metal analysis.

Determination of Heavy Metals by Atomic Absorption Spectrometry (AAS)

Heavy metal concentrations (As, Cd, Cu, Zn, Pb, Ni and total Cr) were determined using Atomic Absorption Spectrometry (AAS), based on the selective absorption of monochromatic radiation by free ground-state atoms in a gaseous phase.

Principle of the Method

Atomic Absorption Spectrometry (Fig. 4) relies on the measurement of light absorption at element-specific wavelengths emitted by hollow cathode lamps. When a sample is atomized in a flame or graphite furnace, ground-state atoms absorb radiation proportional to their concentration, following the Beer–Lambert law.

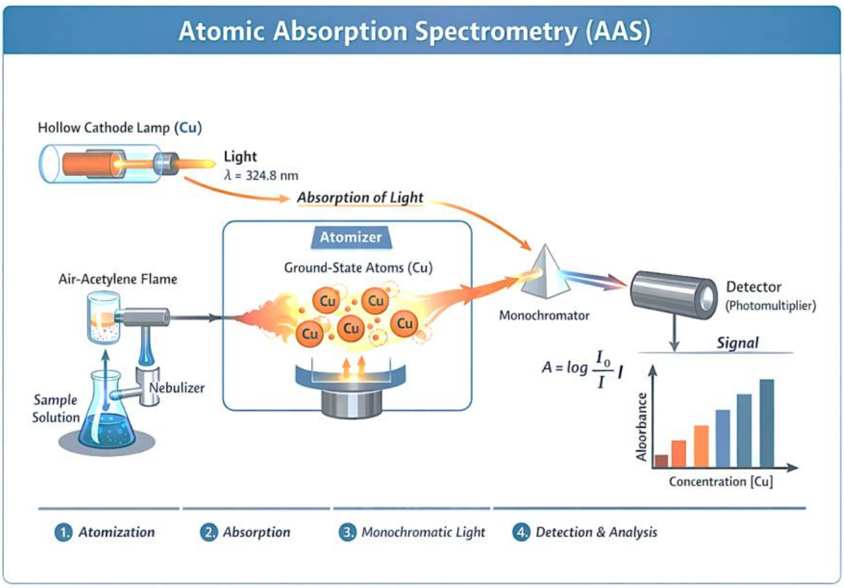

Fig. 4. Schematic diagram of atomic absorption spectrophotometry (AAS) principle[5]

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[5] The figure illustrates the analytical principle of atomic absorption spectrophotometry. A hollow cathode lamp specific to the target element (e.g., Cu, λ = 324.8 nm) emits a characteristic wavelength that passes through the atomized sample in an air–acetylene flame. The sample solution is first nebulized

For the present study, Flame Atomic Absorption Spectrometry (FAAS) was used for Cu, Zn, and Ni due to their relatively high concentrations, whereas Graphite Furnace AAS (GFAAS) was applied for Pb, Cr, As, and Cd when trace-level detection was required.

Sample Preparation

Wastewater samples were acidified immediately after collection to pH < 2 using ultrapure nitric acid (HNO_3, 65%). Prior to analysis, samples were subjected to acid digestion to solubilize particulate-bound metals. Digestion was performed according to American Public Health Association [APHA] (2017) standard methods:

- 50 ml of well-mixed sample was transferred into a digestion flask.
- 5 ml of concentrated HNO_3 was added.

The mixture was heated at 95 °C (without boiling) until volume reduction to approximately 15–20 ml.

After cooling, the digest was filtered (0.45 μm membrane filter) and diluted to 50 ml with deionized water.

All glassware was soaked in 10% HNO_3 for 24 h and rinsed with ultrapure water prior to use to prevent contamination.

Instrumental Conditions

Metal analysis was performed using an Atomic Absorption Spectrophotometer equipped with element-specific hollow cathode lamps (Fig. 5). Typical operating conditions were (Table 1):

Table 1. Analytical conditions used for heavy metal determination by atomic absorption spectrometry (AAS)

Element	Wavelength (nm)	Flame Type
Cd	228.8	Graphite furnace
As	193.7	Graphite furnace
Pb	217.0	Graphite furnace
Cr	357.9	Air–acetylene
Ni	232.0	Air–acetylene
Cu	324.8	Air–acetylene
Zn	213.9	Air–acetylene

This table presents the analytical conditions used for the determination of heavy metals by atomic absorption spectrometry (AAS). It specifies the selected analytical wavelength (nm) for each element and the corresponding atomization technique applied, namely graphite furnace for trace-level detection (Cd, As, Pb) and air–acetylene flame for elements present at higher concentrations (Cr, Ni, Cu, Zn).

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and converted into free ground-state atoms in the atomizer. These atoms absorb part of the incident light proportional to their concentration. The transmitted light is then selected by a monochromator and measured by a photomultiplier detector. The absorbance ($A = \log I_0/I$) is directly proportional to the metal concentration in the sample.

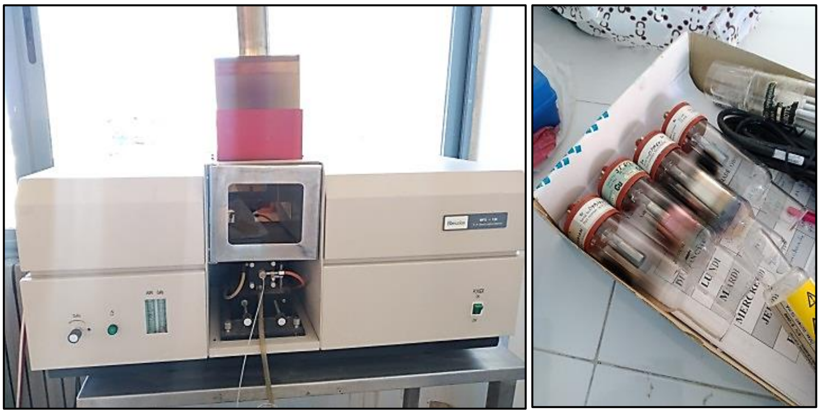

Fig. 5. Atomic Absorption Spectrophotometer (AAS) and its corresponding hollow cathode lamps used for trace metal analysis[6]

Instrument calibration was performed using multi-element standard solutions prepared from certified stock standards (1000 mg/L). Calibration curves were constructed using at least five concentration levels covering the expected range of sample concentrations. The correlation coefficient (R^2) was maintained above 0.995.

Quality Control and Method Performance

Quality assurance procedures included:

- Analysis of reagent blanks
- Duplicate samples
- Spiked recovery tests
- Periodic recalibration after every 10 samples

Limits of Detection (LOD) were calculated as: three times the standard deviation of blank measurements divided by the slope of the calibration curve.

Recovery rates ranged between 90% and 110%, confirming method accuracy. Relative standard deviations (RSD) were maintained below 5% for FAAS and below 10% for GFAAS measurements.

Atomic Absorption Spectrometry was selected due to:

- High selectivity for individual metal determination
- Adequate sensitivity for industrial wastewater monitoring
- Robustness and reproducibility
- Compliance with international standards (APHA, ISO 11885 equivalent methods)

AAS remains a widely accepted reference technique for regulatory monitoring of heavy metals in industrial effluents.

[6] Atomic absorption spectrophotometer used for the determination of Cu, Zn, Ni, Pb, and Cr in water samples. The hollow cathode lamps shown correspond to each analyzed element and provide the specific wavelengths required for measurement.

Results & discussion

Coppersmiths, chemical and health risks

In craft workshops, artisans use several methods and processes such as melting the raw material, firing, modeling, cleaning, and polishing copper items. The use of chemicals such as acid, solvents, thinners, etc. is essential in polishing and nickel-plating copper objects in order to clean them, give them shine, or even protect them from corrosion. These steps are carried out in medium-sized basins (Fig. 6), and the wastewater is randomly discharged into the site's sewers and manholes.

Fig. 6. Water basins used during the treatment and cleaning of copper objects in traditional workshops[7]

Chemical risk -defined as a set of hazards associated with the use of chemicals, which may cause major accidents for humans and environmental pollution (Margossian, 2006) - is one of the most prevalent types of risk in the copperware activity. Our survey showed that these artisans are exposed to multiple health risks related to the use of chemicals and solvents during different stages of manufacturing. 26.7% of coppersmiths report using nitric acid, considered the most widely used, economical, and effective for leaching heavy metals, especially when used in high concentrations (Loughlaımı, et al., 2025), and 20% of them use sulfuric acid to clean residues and rust (International Labor Organization [ILO], 2025). However, none of these artisans confirmed the use of arsenic due to their lack of knowledge about this substance or because it may be known by a common (non-scientific) name (Fig. 7). This point is worth considering given the toxicity of arsenic: it is possible that the fine particles produced by copper smelting contain significant amounts of arsenic (Dosmukhamedov, et al., 2023), which can cause long-term damage related to skin lesions and an increase in mortality rates due to bladder and lung cancer (Quezada, et al., 2024).

[7] The figure shows water-filled basins used in the cleaning and surface treatment processes of copper objects. These basins are employed for rinsing, chemical washing, and removal of residues generated during polishing and finishing stages. The water may accumulate metal particles and chemical additives, potentially contributing to wastewater contamination if discharged without prior treatment.

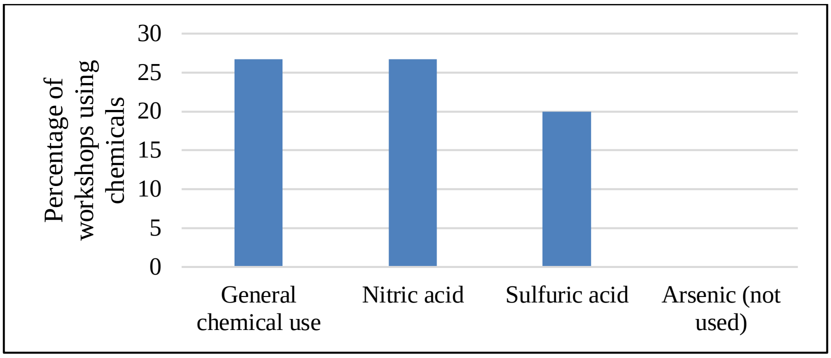

Fig. 7. Percentage of copperware workshops using different chemicals during production processes[8]

Repeated exposure to these substances, combined with inhalation of fumes and particles during polishing and welding, appears to be a key factor in the reported illnesses: 73.3% of craftsmen suffer from allergies, 60% have ear and throat conditions, 46.7% have severe dry coughs, and 40% have chest conditions such as chronic asthma. Skin disorders, particularly burns to the hands, also reflect direct contact with acids and solvents. These high proportions of respiratory and dermatological symptoms indicate a possible correlation between repeated exposure to acids and the health problems observed. Although these data are based on self-reported statements and do not serve as direct evidence of causality, their frequency remains a cause for concern in a sample representing more than 20% of the workshops in the site studied.

With regard to personal protective equipment (PPE) (Fig. 8), 60% of craftsmen wear gloves (often in poor condition), 26.7% say they wear a mask and confirm that it has been suitable since Covid-19, 33.3% wear appropriate footwear, and 40% use a protective apron. Earplugs are used by only 20%, and none of the coppersmiths wear protective eyewear despite irritation or redness of the eyes.

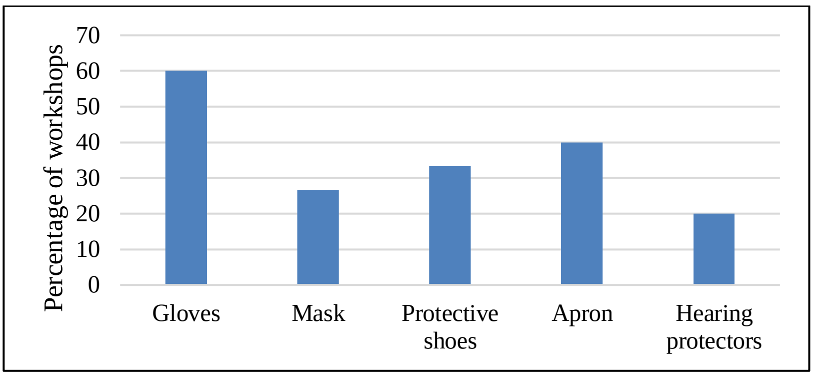

Fig. 8. Percentage of workshops using personal protective equipment (PPE) in copperware craft workshops[9]

[8] Distribution (%) of chemical substances used in copperware workshops, showing predominant use of nitric acid and general chemicals, moderate use of sulfuric acid, and no reported use of arsenic.
[9] Data represent the proportion of surveyed copperware workshops where each type of personal protective equipment (PPE) is used by workers.

These findings are reflected in research conducted among Tambat craftsmen (traditional coppersmiths in Tambat Ali) in India, where the recurrent use of chemicals in the cleaning and treatment of copper is described as a structural component of the craft process. Direct and constant interaction with sulfuric acid, often handled with bare hands, has been reported, with artisans claiming that diluted acid does not affect them, despite visible skin scars. This normalization of chemical risk, integrated into the professional routine, reflects a diminished perception of danger (Boradkar, 2022), comparable to that observed among the coppersmiths of Bardo. However, the Indian study adopts a perspective focused on the technical and sensory relationship between the artisan and the material, without quantifying the health effects, unlike our survey, which highlights the numerical proportions of respiratory and dermatological disorders. Our results suggest, despite the absence of specific biological measurements, that this prolonged interaction with chemicals could be accompanied by measurable health effects, particularly related to the inhalation of toxic fumes and repeated contact with corrosive agents; thus, constituting a structural factor of health vulnerability.

Furthermore, another study conducted in South Africa on artisanal workshops manufacturing cooking utensils from recycled metals highlights worrying levels of exposure to lead and other heavy metals. Blood lead (Pb) concentrations ranged from 1.1 to 4.6 µg/dl, with a median of 2.1 µg/dl, which is significantly higher than the 1.0 µg/dl found in unexposed individuals ($p < 0.0001$). Skin wipe samples taken before and after work also showed a median increase in all 22 elements analyzed, including a 3.5-fold increase in lead load on the hands and a 7.3-fold increase in aluminum after work (Street, et al., 2020).

Although our research does not validate the declared use of arsenic and did not measure heavy metal levels in the blood of artisans, the possibility of indirect exposure through inhalation of melting fumes and skin penetration of contaminants cannot be ruled out. Thus, our results are consistent with a trend observed in several artisanal contexts; where the lack of strict control over raw materials and chemical processes exposes workers to cumulative long-term risks.

Coppersmiths and environmental risks

The water used by coppersmiths in the cleaning and polishing phase is discharged directly into the workshop sewers without prior treatment. To this end, we wanted to measure the pollution level of this water by taking three samples from three different basins. The results are as follows:

Physicochemical parameters of the water in the three samples

The results of the laboratory analyses revealed variations in the physicochemical parameters of the water in the three basins, as illustrated below (Table 2):

Table 2. Physicochemical characteristics of wastewater collected from three traditional copper workshops

Samples	pH	COD (mg/L)	Turbidity (NTU)	TOC (ppm)
1	1.4	6176	60	77.7
2	1.5	220	22	52.9
3	0.2	3265	32	94.9

Source: (Analysis results, 2025)[10]

The pH values appeared to be very low, ranging from 0.2 to 1.5, indicating that the water used in copper processing is highly acidic due to the use of strong and highly concentrated acids such as nitric acid. This acidity can cause rapid corrosion of sewer pipes if wastewater is discharged directly (Fytianos, et al., 2021). A highly acidic pH also promotes the mobility and dissolution of heavy metals in effluents; thereby increasing their ability to disperse into the receiving environment.

In the first and third samples, very high levels of COD (chemical oxygen demand) were noted: 6,176 mg/L and 3,265 mg/L, respectively. This shows that the water is polluted by significant amounts of oxidizable organic and inorganic matter (such as oils, detergents, heavy metals, etc.). Although the second sample recorded a relatively low value of 220 mg/L, this still exceeds the authorized environmental exposure thresholds estimated at COD ≤ 120 mg/L (Journal Officiel de la République Algérienne [JORADP], 2006) and is considered contaminated water that is not suitable for discharge without prior treatment. The significant disparity observed between the samples could be attributed to the various stages of the artisanal process (acid pickling, polishing, rinsing), indicating uneven effluent disposal.

To identify organic contamination in the water used, samples were subjected to total organic carbon (TOC) analysis. The test showed significant values in all three samples, ranging from 52.9 mg/L to 94.9 mg/L. These levels clearly exceed the permitted threshold, which must not exceed 20 mg/L. This can be attributed to the presence of dissolved or suspended organic substances such as oils or solvent residues.

With regard to turbidity, the test revealed moderate to high levels (between 22 NTU and 60 NTU), indicating that the water used is heavily polluted with fine suspended particles such as copper residues.

Heavy metal values recorded in the three samples

Analysis of the three samples taken revealed significant variations in the concentrations of certain heavy metals compared to international standards (Table 3).

[10] This table presents the physicochemical characteristics of the collected wastewater samples. COD (Chemical Oxygen Demand) is expressed in mg/L, turbidity in nephelometric turbidity units (NTU), and TOC (Total Organic Carbon) in ppm. The pH values indicate the acidity level of each sample.

Table 3. Concentrations of heavy metals in wastewater collected from three traditional copper workshops

Substance	Sample 1 (mg/L)	Sample 2 (mg/L)	Sample 3 (mg/L)	Guideline value (mg/L)
Arsenic (As)	0.0122	0.0198	0.1031	0.01
Cadmium (Cd)	0.0025	0.0063	0.0075	0.002
Chromium (Cr)	-	0.007	0.0017	0.003
Copper (Cu)	0.01	0.002	0.0884	0.2
Nickel (Ni)	-	-	-	0.1
Lead (Pb)	0.0031	0.0035	0.01	0.05
Zinc (Zn)	0.01	0.0032	0.06	2

Source: (Analysis results, 2025)[11]

In the samples taken, three heavy metals—arsenic (As), cadmium (Cd), and total chromium (Cr)—significantly exceeded the reference limits (Fig. 9), indicating a significant environmental and health risk. The level of arsenic (As) in the third sample (0.1031 mg/L) exceeded the permitted reference limit (0.01 mg/L). This extremely high value can be harmful to the environment, affecting aquatic organisms even at minimal concentrations (Smedley & Kinniburgh, 2002). For humans, prolonged exposure to arsenic in its inorganic form affects the skin; with changes in pigmentation, skin lesions, and rough patches on the palms of the hands and soles of the feet (hyperkeratosis). These symptoms appear after a minimum exposure period of five years and may be precursors to skin cancer (World Health Organization [WHO], 2022).

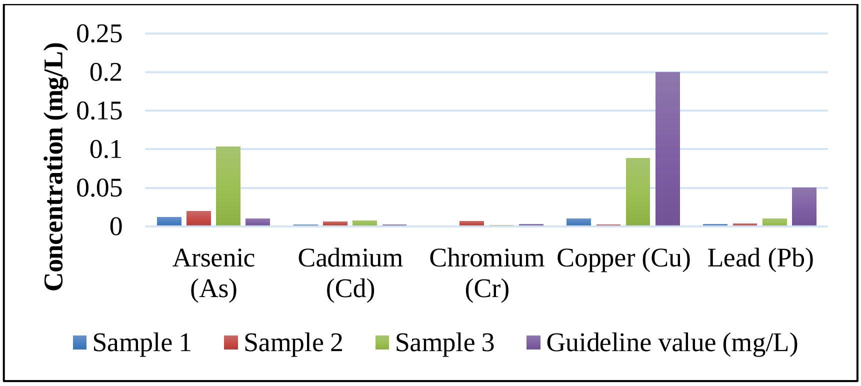

Fig. 9. Concentrations of heavy metals (mg/L) measured in three water samples compared with guideline values[12]

[11] This table presents the concentrations of heavy metals (mg/L) measured in the three wastewater samples and their comparison with international guideline values. The symbol (–) indicates that the metal was not detected in the sample, i.e., its concentration was below the detection limit of the analytical method.

[12] This figure illustrates the concentrations of selected heavy metals (Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), and Lead (Pb)) measured in three water samples, expressed in mg/L.

Cadmium (Cd) also exceeded the guideline value (0.002 mg/L) in all three samples, reaching 0.0075 mg/L in the third sample, confirming its toxicity, its accumulation in the food chain... and its capacity to cause large-scale environmental and health damage; particularly to aquatic flora and fauna (Jarup, 2003). It can lead to kidney stones, softening of the bones, or severe lung disease in cases of prolonged inhalation (Organisation mondiale de la Santé [OMS], 1986).

Chromium (Cr), which was slightly overabundant in the second sample (0.007 mg/L), could be associated with potentially harmful effects on microorganisms (McLean & Bledsoe, 1992). It can also harm workers exposed to high concentrations of chromium; causing an increased risk of lung and digestive tract cancer (OMS, 1986).

In a study on optimizing wastewater treatment from brass workshops in the city of Fez, Morocco, effluents showed very high levels of nickel (up to 150.94 mg/L) and copper (10.64 mg/L) (Laidi, et al., 2015); while in our study, the concentrations of copper (0.0884 mg/L) and lead (0.01 mg/L) remained well below critical thresholds. However, these metals can be toxic to sensitive aquatic organisms (Förstner & Wittmann, 1981) and can accumulate biologically over the long term -even at low concentrations- causing lasting environmental impacts, depression, fatigue, mild abdominal discomfort, irritability in adults, anemia in children, and behavioral changes if subjects are poisoned by these substances (OMS, 1986).

As for nickel (Ni), its concentration was not detectable in any of the samples; which is a positive indicator. Zinc (Zn) concentrations were far from toxic (Fig. 10); thus, minimizing the risk of environmental impact, highlighting marked differences in the heavy metal contamination profile of artisanal effluents depending on local processes and contexts.

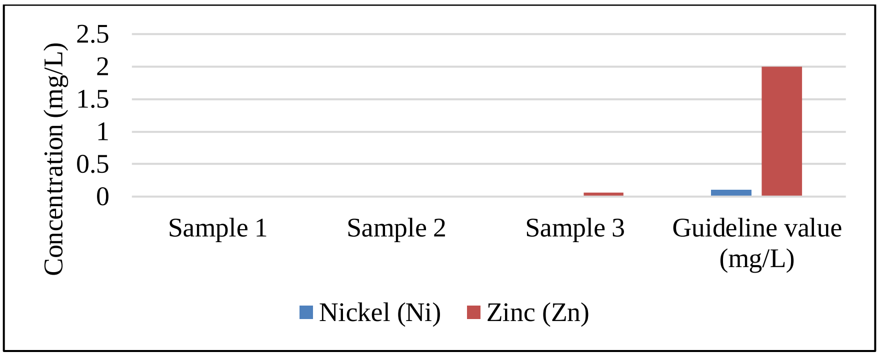

Fig. 10. Concentrations of Nickel (Ni) and Zinc (Zn) in three water samples compared with guideline values[13]

This contamination pattern -with three metals exceeding the thresholds (As, Cd, and Cr) and others present in moderate concentrations (Cu, Pb, Zn, Ni)- reflects the nature of

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The results are compared with the corresponding guideline values (mg/L) to assess compliance with recommended limits. The bars represent measured concentrations in each sample, while the guideline values indicate the maximum permissible levels for each metal.

[13] This figure presents the concentrations of Nickel (Ni) and Zinc (Zn) measured in three water samples, expressed in mg/L. The measured values are compared with their respective guideline limits (mg/L) to evaluate compliance with recommended standards. The bars represent the concentrations detected in each sample, while the guideline values indicate the maximum permissible levels. The results show that Ni and Zn were detected at very low concentrations in all samples relative to their corresponding guideline values.

various manufacturing and recycling processes for copper items, where the intensive use of chemicals and pastes, welding, polishing, and direct wastewater disposal concentrate certain toxic elements in the environment.

The discharge of this polluted water from the copper workshops, rich in substances harmful to health and the environment, without prior treatment, combined with other liquid waste from urban and agricultural activities around Oued Rhumel, increases the risk of contamination of ecosystems that are in direct contact with this water. Studies reveal that significant concentrations of heavy metals have been recorded at five sediment points in Oued Rhumel (upstream and downstream of the city): (3125 mg/kg) for copper, 1570 mg/kg for zinc, and 199.5 mg/kg for cadmium, exceeding the environmental quality thresholds for sediments according to Sediment Quality Guidelines (SQG) standards (Chabour, 2018). Lead and nickel were also found in high concentrations (48.3 and 69.3 mg/kg, respectively). Another study confirms that at the level of Oued Rhumel and Oued Boumerzoug (a tributary of Rhumel), the average content of trace metal elements in surface sediments reveals an enrichment of lead (Pb), zinc (Zn), and cadmium (Cd), despite the latter's relative rarity. Mineral and organic particles migrate to the bottom and are deposited in sediments, which act as reservoirs of pollution and become potential sources of contamination (Afri-mehennaoui, et al., 2009). These results are consistent with observations from several studies conducted in other artisanal and semi-industrial contexts. In the industrial zone of Suame (Ghana), land near several metalworking, auto repair, and ironworking workshops showed significant enrichment in Pb, Cu, Zn, and Cr attributable to artisanal activities (Felix et al., 2018); reflecting a contamination pattern similar to that observed in Oued Rhumel. Similarly, in the Bagega region (Zamfara, Nigeria), the soil and water at artisanal gold mining sites showed high concentrations of Pb, Ni, and Hg; illustrating the direct impact of artisanal activities on the surrounding environment (Nuhu, et al., 2014) and suggesting that metallurgical and artisanal activities contribute recurrently to a pattern of heavy metal contamination, even in varied geographical contexts.

It should be noted that the limited number of samples and restricted geographical coverage mean that the results cannot be generalized to all workshops in Constantine. Nevertheless, these data provide relevant information on contamination patterns and associated risks, and form a basis for considering broader and more systematic investigations in similar workshops; including those that use other chemical techniques, such as electroplating for coating copper items. This process may reveal higher concentrations of nickel (Ni), hexavalent chromium (Cr VI), and other potentially toxic metals; highlighting that occupational and environmental exposure varies depending on the type of tasks performed and the substances handled.

Conclusion

Working in hazardous and occupational metal contamination environments pose a real threat to the health of workers, local communities, and the environment. Although copperware manufacturing preserves Constantine's cultural identity, contributes to heritage conservation and generates jobs, it has a negative impact on the health of artisans and the environment. The coppersmiths of Bardo continuously use chemicals in various tasks related to their craft, exposing themselves to chemical risks for long hours during their work and throughout their entire working lives. The failure to take preventive measures (wearing protective gloves, masks, and goggles) significantly affects their physical and mental health in the long term, with many suffering from allergies, coughs, asthma, and headaches.

As for the environment, the direct discharge subject to treatment of wastewater from copperware manufacturing, which is rich in toxic substances, into the sewers is detrimental to the sustainability of nearby ecosystems such as the Bardo urban park and Oued Rhumel, located downstream from the copperware manufacturing site. Therefore, the results of these samples can be considered a preliminary indicator that requires further research covering a larger number of workshops to assess the environmental impact. On the other hand, sediments revealed high levels of heavy metal pollution, including copper, cadmium, and zinc; exceeding environmental quality standards and suggesting long-term industrial accumulation in the environment.

These results highlight the importance of studying the impact of copper craftsmanship on health and the environment. Environmental education, raising awareness of health risks, and improving working conditions for coppersmiths are solutions that need to be implemented to create a healthy working environment and ensure sustainable productivity. It is necessary to monitor this site and require the installation of effective wastewater treatment units to reduce heavy metal leaks into the environment and encourage innovation in the field of environmental- friendly chemicals that are less harmful to the health of artisans and ecosystems. Furthermore, these findings have important implications for public policy and environmental health in craft industries. They highlight the need to implement regulations aimed at protecting the health of artisans, limiting environmental contamination, and promoting sustainable craftsmanship that reconcile cultural heritage preservation, health and ecological safety, and the relevance of these measures for all craft industries.

Conflict of Interest: The authors declare no conflict of interest.

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