The Association between Covid-19 and heavy metal pollution in Iraqi cities from hierarchical prediction

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An assessment was carried out of the relationship between the Corona Virus (covid-19) and the spread across Iraq of various heavy metal contaminations. At the onset, all the confirmed, recovered and death cases of covid-19 virus in Iraq up to the date of May, 2nd, 2020 were collected and compared with the top three infected countries in the world (USA, Spain and Italy). On the other hand, numerous heavy metal contaminations in different Iraqi cities have been summarized and associated with allowable upper and lower worldwide standard limits. In addition, the study introduced a hierarchical predictive approach for the relationship between confirmed and death cases of covid-19 viruses with heavy metal contamination in various Iraqi cities. It was concluded that all the studied Iraqi cities have heavy metal contamination for different chemical elements exceeding the allowable standard limits. In addition, it was shown that the extreme contents of Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc (Zn) are concentrated in Al-Qadisiyah, Al-Sulaimaniyah, Erbil and Baghdad cities with limits of 160 µg / g, 240.9 µg /

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Keywords: covid-19 confirmed cases, heavy metal contamination, distinctive Iraqi cities, heavy metal standard limits, hierarchical prediction approach.

Introduction

Corona Virus (Covid-19) has started in Wuhan city, Hubei Province, China for the first time and reached the entire world (Tosepu et al. 2020; Malay et al. 2020 (a)). Coronaviruses are part of the Coronaviridae group and they are single-strand enveloped viruses with a Ribonucleic Acid (RNA) genome of approximately 26-32 kb in volume (Clement et al. 2020). It was stated that covid-19 could be a result of evolving or re-evolving diseases defeating animals, human and both (El-Sayed and Kamel 2020; Malay et al. 2020 (b)). On the second of May, 2020, Iraqi officials have reported 2153 confirmed cases for covid-19 virus since the beginning of the pandemic. In Iraq, the top three cities with covid-19 confirmed accumulative cases are Baghdad (384), Al-Najaf (303), and Al-Basrah (281) cities. Normal indications for covid-19 virus contain signs of severe breathing complaints, including high temperature accompanied with both difficulties in breath and coughing. The maturation sickness period ranges from 5 to 14 days where severe cases initiate critical breathing, pneumonia, kidney breakdown, and death. The preliminary clinical indications have shown that the widely cases are fever, and few cases straggle from troubles in breathing with massive pneumonia infiltration in both lungs (Holshue et al. 2020; Perlman 2020; Lorika and Stefan 2020). The medical signs of such harsh and dangerous covid-19 disease are reasonably similar to the Middle East Respiratory Syndrome (MERS) and Severe

Acute Respiratory Syndrome (SARS) (Wang et al. 2020b). In the earlier studies, it was observed that several factors such as wind speed for two weeks before the widespread of the covid-19 virus and daily temperature have strong influences on the population (Şahin 2020; Bashir et al. 2020). In addition, it was shown that Auto Regressive Integrated Moving Average (ARIMA) model has been used to predict the future time evolution of the covid-19 case count in different countries (Ceylan 2020). In Iraq, no studies have tried to investigate the environmental issues and their associations with the spread of covid-19.

Toxic heavy metal and radionuclide pollution has been a major health and political problem (Guo et al. 2016). In the recent years, the problems of the environmental pollution in Iraq have increased, especially heavy metal pollution (Al-Janabi et al. 2019). Metals with high rates have been released into the ecosystem. Such heavy metals represent severe contaminants because of their toxicity, firmness, and bioaccumulation harms (Sahar et al. 2020). The tremendous metal concentrations are toxic and capable to withstand degradation with probable inhibit for a long time in the system where most of such heavy metals can be considered as the physical elements of the earth's shell (Volpe et al. 2020). However, the heavy metals involve in rock weathering that dissolves in water (Mokhtar et al. 2015; Luo et al. 2020).

The contamination that caused by heavy metals in both agricultural and urban soils or water arises from sources such as manufacturing, mining, paints, pesticides, batteries, automobiles, domestic and industrial sludge (Tawfiq and Ghazi 2017; Wang et al. 2020a; Uma et al. 2020). It was shown that using the sedimentation tank method could remove heavy metals by 70%, while these methods facilitate building up heavy metals in the traps, ponds and tanks generating a toxic waste product that is difficult to eliminate (Cairns et al. 2020). Soils can contain heavy metals either from its natural geological sources or from the human made sources such as fertilizers, industrial wastes, deposits, and irrigation (Liu et al. 2020). Sources such as energy productions, human anthropogenic actions, waste removal, manufacturing releases, and vehicle discharges would accumulate deposits of heavy metals on any urban surface. Natural soils from different places such as urban areas, landfills, and gas and oil locations might influence human health since such soils could include anthropogenic contaminations (Steffan et al. 2018). Another crucial soil pollution factor is crude oil obtained from processing of oil production and the wastes of oil productions. Several vital metals represented by cadmium, copper, iron, lead, manganese, nickel, and zinc are the major heavy metal pollutants in the water. The levels of heavy metals and accumulated sediments in the rivers have increased because of increasing the release of massive amounts of industrial and domestic wastes into the system.

The presence of heavy metal ions in wastewater with large amounts causes pollution to organism where copper (Cu(II)) entertained a great fraction (Awual et al. 2019). The Cu(II) ion is an essential element in both chemistry and biochemistry for many uses. Nevertheless, the extra Cu(II) ions can quickly present progress to harm for human being, plants and animals even at the low-levels. Extreme Cu(II) ion can alter the redox state of intracellular environment, spoiling cellular structural performance and conducting cell destruction. Moreover, exposure to a huge amount of Cu(II) might initiate health problems starting from stomach distress to brain harm. Thus, the maximum acceptable limit is accurately adjusted where permissible Cu(II) ion in drinking water is 0.05 mg/L.

Human toxicity might be resulted from the sources of the soil supplies as the soil has a great impact on the health of the humans. Based on the soil conditions, the soil can affect human's life positively or negatively. For any necessary element for human health, there is an ideal limit that the body requires and having any concentration above such limits can cause toxicity (Green et al.

2016). As the contaminated soil is irrigated to crop plants and foods, such obtained fruits or vegetables are considered as sources for the risk against human health (Jankaite 2009). Since soil can afford miscellaneous nutrients for human beings, it is able to deliver dangerous ingredients to the bodies through the eaten food (Oliver and Gregory 2015). Thus, the health of human beings can be affected by chemically contaminated soil.

Heavy metals can be released from surficial sediments of water to the upper water environment and thus they can be used intentionally for irrigation processes accompanied with harmful impact to the fishes in the water (Yin et al. 2020). The food characteristics accompanied by the risk against human health are mainly affected by type of agricultural production where the quality of such production is controlled by the type of soil and its metal contamination level (Hadia and Ahmed 2018). Heavy metals perform as harmful materials as they gathered in accumulations in the tissues of the human body (Kirchmann et al. 2017).

It was also shown that the existence of manganese ions (Mn^{+2}) in ingesting water affects supply pipes to clog because of the oxidation of Mn^{+2} to MnO_2, resulting a black color with metallic taste occurred in the water and discoloration in the household, and washing fixtures (Asiri et al. 2018). Continuing exposure to high concentration of Mn^{+2} is hazardous and can hurt human health, causing mood swings and depression.

In general, heavy metals are metallic chemical elements with high atomic masses and densities. Some of the heavy metals are essential to the human body at low levels, whereas they could cause poisoning at higher levels. Frequently, a density of at least 5 gm/cm3 is used to describe a heavy metal. Moreover, heavy metals involve an atomic mass greater than 23 or an atomic number more than 20. Investigating the periodic table of chemical elements, heavy metals dominate the columns 3-16 of the periods 4 to 6, including the transition metals, post-transition metals, and lanthanides (Duffus 2002). There are more than 50 constituents of heavy metals where only 17 of them are classified as toxic elements (Cano et al. 2013; Khan et al. 2020). Lead and cadmium are two of the most dangerous elements against human health and such constituents can cause different disease such as cough, headache, vomiting, and deadly chest pain.

Lead is one of the most widespread soil contaminations all around the world since sources such as lead-based paints, leaded gasoline, various industrial activities, and lead smelting and mining provide leads to the soil (Balabanova et al. 2017). The lead affects the health of children and cause several combined health issues. Urban soil contaminated with lead is a major source for causing health problems to the kids (Li et al. 2015). Fertilization combined with sewage sludge or industrial activities are the main sources of cadmium contaminations in the soil (Nordberg et al. 2014) where the Chinese soil is mostly contaminated with Cadmium. Cadmium contaminated soil has caused the itai-itai disease eruption in Japan in the first part of the past century (Nordberg et al. 2014). As the nitrogen is primarily necessary for the plants in the soil, however; its overuse or inappropriate use can cause a leaching of such excess nitrate into surface or groundwater leading to severe toxicity because of forming nitrite (Zhang et al. 2015). Nitrite has the tendency to react with haemoglobin and form methemoglobin that avoids oxygen from being transported through the entire body. Iron shortage leads to anaemia since it is a vital element of haemoglobin. Around two billion people all over the world straggle from a deficiency of iron. In addition, the over rate of iron can cause metabolic and genetic diseases (Fraga 2005). Zinc deficiency initiates the negative effects on several body abilities such as the immune system response, the healing of wounds, and capability of both smell and taste (Fraga 2005). Depending on the basis of cation exchange capacity, the silver nanoparticles have been used to remove heavy metal ions of Pb from water (Khan et al. 2013).

In the recent years, the world advancement has caused environmental pollution since the concentrations of heavy metals in urban areas have passed their originating standards (Duan et al. 2018). The substances of Cadmium (Cd), Copper (Cu), and Zinc (Zn) have altered the nature of the soil from uncontaminated condition to tolerably contaminated condition. It was reported that the species of the inhabitant plants have the tendency to phytoremediation of Cd, Chromium (Cr), Cu and Lead (Pb) contaminated soils. However, other studies have demonstrated an environmental biological toxicity with substantial heavy metals represented by Arsenic (As), Cr, Cu, Nickel (Ni), Tin (Sn), and Zn (Liu and Chen 2018). Moreover, the current studies have shown that the air-polluted countries are more vulnerable to face covid-19 virus, which expects a positive relationship between contaminations and covid-19 virus (Albuquerque et al. 2020). It is worthwhile to mention that anions have many positive effects on human health such as binding red blood cells and increasing the oxygen intake, decreasing the blood pressure, increasing rate and forcing the contraction of the heart (Im et al. 2018). Thus, it is believed that anions should have no negative impacts on the human health and no possible relation with covid-19 could be found.

Different cities in Iraq are under the threatening of heavy metal pollution in the absence of standard environmental rules and regulations especially cities with high population. For instance, Baghdad has the highest population estimated by almost seven million persons in 2011 and such population is a reason for an intensive anthropogenic conducts (DWUA 2014). In addition, an attention about crude oil wastes should be taken care after the progression of petroleum subdivision in the northern share of Iraq (Ahmed and Gulser 2019). In the sense of such Iraqi environments; construction workers, farmers, and miners are in touch with such soils and their health are exposed to risk with different rates. Hence, the process of heavy metal assessment plays a crucial role in Iraqi environmental pollution studies.

The PM is defined as a set of particles diffused in the air for adequate time to be dispersed and transferred. PMs are inhalable corpuscles that produce distinctive destruction to human health due to their small sizes. The toxicity of PMs is amplified since they are able to absorb other constituents such as polycyclic aromatic hydrocarbons and heavy metals. Hydrocarbons are obtained from oil and are superior in concentration during winter season. Heavy metals are ordinary components of the earth's crust. Most of the heavy metals are toxic such as arsenic, cadmium, chromium, lead, mercury, and uranium. Heavy metals are the main reasons for the cardiovascular systems. Cardiovascular effects are caused by PM and associated with the deposition of particles in the lungs where their translocations in the air-blood barrier cause systemic inflammation. Thus, the heavy metals can have a strong association with covid-19 where both can induce a drastic harm to the lungs and threaten the human life.

The complication connections of human life associated with both covid-19 virus and contamination caused by different heavy metals have created the focus for investigating this analysis. In addition, no previous studies have tried to examine such assessment in Iraq. The novelty of this work can be achieved through providing a mathematical relationship between confirmed and death cases of covid-19 with individual distribution of heavy metals in Iraq. The used mathematical correlation is derived using a comprehensive survey of heavy metal distributions in various Iraqi cities, as well as confirmed and death cases of covid-19 recorded over a specific period of time. Hence, the main objective of this study was to inspect the parallel distribution for both covid-19 virus and heavy metal contamination all over Iraqi cities depending on available data. Specifically, the study has tried to check the relationship between covid-19 virus and heavy metal contamination in different Iraqi cities using a hierarchical predictive approach.

Methods

Study area

Iraq occupies the heart of the Middle East, where Baghdad is the capital city with the highest population compared to other cities in the country. The capital of Iraq lies in the latitude of 33.312805 and longitude of 44.361488. The total area of Iraq is 437,072 km^2 and consists of 18 provinces. Based on the data of 2018, the total population is Iraq is 38.43 million persons with an annual growth rate of 2.3%.

Data collection

The numbers of covid-19 cases in Iraq have been collected from the first case up to the date of May 2nd, 2020. In addition; the details of the confirmed cases, cases per million of each city, recovered cases and deaths have been assembled. The process of heavy metals contamination has included summarizing several worldwide standards as shown in Table 1. Moreover, the details of heavy metals contamination in all Iraqi cities have been summarized in Table 2.

Results and discussion

Covid-19 cases

The total confirmed covid-19 cases to the entire population in Iraq up to May 02, 2020, compared with the three top countries in the world have shown in Fig. 1 (a). It is clearly shown that Iraq had a rate of 0.004% for the total confirmed cases / population, whereas Spain had the highest rate of 0.461% for the total confirmed cases / population. However, both USA and Italy had almost the same rate of the total confirmed cases / population up to 0.344%. The total death covid-19 cases to the entire population in Iraq up to May 02, 2020, compared with the three top countries in the world have shown in Fig. 1 (b). It is obviously revealed that Iraq had the lowest rate of total death cases / population of 0.0002% compared with the three top countries. Nevertheless, Spain had the highest death / population cases of 0.0534%, followed by 0.0467% and 0.0199% for both Italy and USA respectively. The total recovery covid-19 cases to the entire population in Iraq up to May 02, 2020, compared with the three top countries in the world have shown in Fig. 1 (c). As it is presented in Fig. 1 (c), Iraq had the lowest recovery cases / population of 0.003% compared to Spain that had the highest recovery cases / population of 0.249%. In addition, it is worthwhile to point out that the recovery cases / population were 0.129% and 0.0431% in both Italy and USA respectively.

The total confirmed covid-19 cases in all Iraqi cities up to May 02, 2020, have shown in Fig. 2 (a). The capital of Iraq (Baghdad) had the highest confirmed cases followed by Al-Najaf, Al-Basrah, Erbil, and Al-Sulaymaniyah cities. The confirmed cases in the Iraqi top cities range from 384 cases in Baghdad to 138 cases in Al-Sulaymaniyah and this mainly because these five cities have international airports that facilitated the virus entrance with limited health monitoring systems in such airports. The total confirmed covid-19 cases per million of the city population in all Iraqi cities up to May 02, 2020, have shown in Fig. 2 (b). The highest rate for the total confirmed covid-19 cases per million of the city population was in Al-Najaf city and up to 216 whereas the lowest rate was recorded in Al-Anbar. In addition, Dohuk and Al-Basrah are the two cities with no reported numbers for the total confirmed covid-19 cases per million of city population. It is meaningful to recognize that Al-Najaf city is a crowded place since it holds one of the important Islamic shrines. The total recovered covid-19 cases in all Iraqi cities up to May 02, 2020, have shown in Fig. 2 (c). The Al-Najaf city had the highest recovered cases of 270 while Salah al-Din city had the lowest recovered cases with one case only. The total deaths of covid-19 cases in all Iraqi cities up to May 02, 2020, have shown in Fig. 2 (d). Baghdad city had the highest deaths of 30 followed by Al-Basrah, Al-Najaf, and Karbala with deaths of 17, 6, and 6 respectively.

Heavy metal contamination

For heavy metal representation, the obtained data from Table 2 have been drawn all over the country. The distribution of cadmium (Cd) element in different Iraqi cities is shown in Fig. 3 (a). Based on the collected data, Dohuk city has the highest Cd content with a concentration of 56.52 µg / g (61% of the total Cd concentration in all Iraqi cities). The main reason for the high Cd concentration in Dohuk city is attributed to the recently working oil companies with inadequate obligations toward the environmental rules. The average reported Cd concentration for an area with coal power plants is 0.06 µg / g which is much lower than most of Iraqi cities (Okedeyi et al. 2014). Thus, more limitations and regulations should be applied to minimize the increase of Cd concentration in Iraqi cities.

Similarly, the distributions of chromium (Cr) and copper (Cu) elements are shown in Fig. 3 (b) and (c) respectively. It can be noticed that Wasit, Thi Qar, and Al-Sulaimaniyah are the top three Iraqi cities with a Cr concentration of 425.2 µg / g, 418 µg / g and 300.6 µg / g respectively. The consecutive Cr concentration in Wasit, Thi Qar, and Al-Sulaimaniyah cities represents 25%, 24%, and 17% of the total Cr concentration in all Iraqi cities. In addition, it can be observed that Al-Qadisiyah, Thi Qar, and Mosul cities are the top three Iraqi cities with Cu concentrations of 160 µg / g, 144 µg / g and 135 µg / g respectively. The consecutive Cu concentration in Al-Qadisiyah, Thi Qar, and Mosul cities represents 16%, 14%, and 13% of the total Cu concentration in all Iraqi cities. The average reported Cr and Cu concentrations for an area with coal power plants are 63.27 µg / g and 56.15 µg / g respectively (Okedeyi et al. 2014). It is noted that the recorded Cr and Cu concentrations in Iraqi cities are higher than the reported values. Hence, the increase of both Cr and Cu concentrations should be controlled by Iraqi authorities to prevent any upcoming environmental catastrophe.

The distributions of nickel (Ni), lead (Pb) and zinc (Zn) elements are shown in Fig. 4 (a), (b) and (c) respectively. It can be noticed that Al-Sulaimaniyah, Wasit, and Al-Qadisiyah are the top three Iraqi cities with a Ni concentration of 240.9 µg / g, 226.6 µg / g and 200 µg / g respectively. The consecutive Ni concentration in Al-Sulaimaniyah, Wasit, and Al-Qadisiyah cities represents 12%, 11%, and 10% of the total Ni concentration in all Iraqi cities. In addition, it can be observed that Erbil, Kirkuk, and Mosul cities are the top three Iraqi cities with a Pb concentration of 378 µg / g, 341.44 µg / g and 289.6 µg / g respectively. The consecutive Pb concentration in Erbil, Kirkuk, and Mosul cities represents 20%, 18%, and 15% of the total Pb concentration in all Iraqi cities. Moreover, it can be noticed that Baghdad, Al-Muthanna, and Thi Qar cities are the top three Iraqi cities with Zn concentration of 1080 µg / g, 407 µg / g and 310 µg / g respectively. The consecutive Zn concentration in Baghdad, Al-Muthanna, and Thi Qar cities represents 32%, 12%, and 9% of the total Zn concentration in all Iraqi cities. The average reported Ni, Pb and Zn concentrations for an area with coal power plants are 31.79 µg / g, 52.05 µg / g and 86.49 µg / g respectively (Okedeyi et al. 2014). It is noted that the recorded Ni, Pb and Zn concentrations in Iraqi cities are higher than the reported values. The current Ni, Pb and Zn concentrations portend for an upcoming environmental disaster in Iraq.

A comparison between the heavy metal distribution with upper and lower allowable standard limits has been investigated. The variation of Cd element distribution compared with standard allowable limits has been shown in Fig. 5 (a). It is clearly shown that places such as Dohuk, Babil and Mosul cities have Cd concentrations higher than the allowable upper limit. The Cd concentration rate has exceeded the allowable upper limit by 30, 6, and 5 times in Dohuk, Babil and Mosul cities respectively.

Similarly, the variation of Cr element distribution compared with standard allowable limits has been shown in Fig. 5 (b). It is obviously indicated that cities such as Wasit, Thi Qar, and Al-Sulaimaniyah have Cr concentrations higher than the allowable upper limit. The Cd concentration rate has exceeded the allowable upper limit by almost 3, 3, and 2 times in Wasit, Thi Qar, and Al-Sulaimaniyah cities respectively.

The variation of Cu element distribution compared with standard allowable limits has been shown in Fig. 6 (a). Several Iraqi cities have exceeded the allowable upper limit such as Thi Qar, Mosul, Kirkuk, Baghdad, Al-Qadisiyah, Erbil, and Babil. It is noticeably shown that Al-Qadisiyah, Thi Qar and Mosul cities have the highest Cu concentrations compared to other Iraqi cities. The Cu concentration rate has exceeded the allowable upper limit by almost 2, 1.9, and 1.8 times in Al-Qadisiyah, Thi Qar, and Mosul cities respectively.

The variation of Ni element distribution compared with standard allowable limits has been shown in Fig. 6 (b). Most of the cities have Ni concentrations higher than the upper allowable limit where the Thi Qar city had the highest Ni concentration exceeding the upper allowable limit by 9.9 times. In addition, Al-Sulaimaniyah and Wasit cities have exceeded the Ni allowable upper limit by 4.8 and 4.5 times respectively.

The variation of Pb element distribution compared with standard allowable limits has been shown in Fig. 7 (a). All of the Iraqi cities have a Pb concentration with different rates where nine of the cities have Pb concentration higher than the allowable upper limit. It can be recognized that Erbil, Kirkuk and Mosul are the top three Iraqi cities that exceeded the Pb allowable upper limit. The Pb concentration rate has exceeded the allowable upper limit by almost 5.4, 4.9, and

4.1 times in Erbil, Kirkuk and Mosul cities respectively.

The variation of Zn element distribution compared with standard allowable limits has been shown in Fig. 7 (b). Eight of Iraqi cities have Zn concentration higher than the allowable upper limit. It can be denoted that Baghdad, Al-Muthanna and Thi Qar are the top three Iraqi cities that exceeded the Zn allowable upper limit. The Zn concentration rate has exceeded the allowable upper limit by almost 7.2, 2.7, and 2.1 times in Baghdad, Al-Muthanna and Thi Qar cities respectively.

As an overall assessment, different Iraqi cities have various heavy metal contaminations. It is worthwhile to mention that Diyala had the highest Iron (Fe) concentration of 16650 µg / g as it was clearly summarized in Table 2.

Relation between covid-19 and heavy metal contamination

Based on the reported information regarding both covid-19 and heavy metal distribution, a suitable hierarchical predictive statistical approach has been proposed. The proposed hierarchical prediction model is based on the fact that the increase in heavy metal contamination can increase the rate of death resulting from lowering human body resistance. Similarly, the covid-19 exhibits the same trend in terms of weakening the human body's resistance. Hence, a linear accumulative hierarchical statistical model has been proposed assuming the accumulative confirmed or death covid-19 cases are linearly proportioned to the accumulative heavy metal concentration. The proposed model has the following form:

$$\frac{\sum(\mathbf{Conf.Cases})_{\mathbf{i}}}{\sum(\mathbf{Conf.Cases})}(\%) = \mathbf{A} + \mathbf{B} * \frac{\sum(\mathbf{Heavy\ Metal\ Concentration})_{\mathbf{i}}}{\sum(\mathbf{Heavy\ Metal\ Concentration})}(\%) \quad \textbf{(1)}$$

Where: $\sum(\text{Conf. Cases})_{\text{i}}$ is the accumulative sum of the confirmed cases of covid-19, $\sum(\text{Conf. Cases})$ is the total sum of the confirmed cases of covid-19, A & B are arbitrary constants, $\sum(\text{Heavy Metal Concentration})_\text{i}$ is the accumulative sum of a specific heavy metal concentration, $\sum(\text{Heavy Metal Concentration})$ is the total sum of a specific heavy metal concentration.

A similar proposed statistical model can be applied for death cases of covid-19. The statistical model for death cases of covid-19 is as follows:

$$\frac{\sum(\textbf{Deaths})_\textbf{i}}{\sum(\textbf{Deaths})}(\%) = \mathbf{A} + \mathbf{B} * \frac{\sum(\textbf{Heavy Metal Concentration})_\textbf{i}}{\sum(\textbf{Heavy Metal Concentration})}(\%) \quad \textbf{(2)}$$

Where: $\sum(\text{Deaths})_\text{i}$ is the accumulative sum of the deaths of covid-19, $\sum(\text{Deaths})$ is the total sum of the deaths of covid-19.

The accuracy of the suggested statistical models (Eqs. 1, and 2) has been evaluated depending on the coefficient of determination (R^2). The coefficient of determination (R^2) is defined as follows:

$$\mathbf{R^2} = \left(\frac{\sum_\mathbf{i}(\mathbf{x_i}-\bar{\mathbf{x}})(\mathbf{y_i}-\bar{\mathbf{y}})}{\sqrt{\sum_\mathbf{i}(\mathbf{x_i}-\bar{\mathbf{x}})^2}\sqrt{\sum_\mathbf{i}(\mathbf{y_i}-\bar{\mathbf{y}})^2}}\right)^\mathbf{2} \quad \textbf{(3)}$$

Where: y_i is the actual value, x_i is the predicted value from the statistical model, $\bar{y}$ is the arithmetic mean of the actual values, $\bar{x}$ is the arithmetic mean of calculated values and N is the total number of the data.

All the proposed statistical models have been validated using the reported Iraqi covid-19 data with the various heavy metal concentrations in different Iraqi cities. Several random variations (gradual increase) were investigated for both covid-19 cases and heavy metal concentrations, and the best distribution with the highest R^2 was chosen. The variations of the covid-19 with the Cd concentration for confirmed and death cases have shown in Fig. 8 (a and b). In addition, the model parameters for confirmed and death cases with respect to all heavy metal variations have summarized in Table 3. It is clearly shown that the proposed statistical models have predicted the variations of the confirmed and death cases very well with a value of (R^2) reached to 0.84 (Table 3). The variations of the covid-19 with the Cr concentration for confirmed and death cases have shown in Fig. 9 (a and b). The suggested statistical models have predicted the variations of the confirmed and death cases very well with a maximum value of R^2 of 0.89 (Table 3). Similarly, the variations of the covid-19 confirmed and death cases with Cu, Ni, Pb and Zn concentrations have been shown in Figs. 10 (a and b), 11 (a and b), 12 (a and b), and 13 (a and b) respectively. The proposed statistical models have predicted the variations of confirmed and death cases very well and this is true for all the various heavy metal concentrations. The maximum obtained R^2 for the variations with Cu, Ni , Pb, and Zn were 0.91, 0.91, 0.95, and 0.97 respectively.

Based on the results of the proposed statistical models, there is a positive linear relationship between the confirmed and death covid-19 cases with the different types of heavy metal distribution. This indicates that increasing any type of heavy metal concentration beyond the allowable upper limit may result in increasing covid-19 confirmed and death cases.

Up to the facts that have been recorded regarding both covid-19 victims and heavy metal contamination distribution, several Iraqi cities might be under a real threaten of such severe heavy metal pollution that have harsher consequences rather than covid-19 virus. In addition, the distribution of heavy metal contamination would weaken the human immunization system that might reflect an increase of covid-19 cases in such places in the short or long-term evaluation.

Conclusions

In this study, the effects of both covid-19 and heavy metals distribution in all Iraqi cities up to May, 2nd, 2020 have been investigated. In one hand, the details of confirmed and recovered cases with total deaths in all Iraqi cities have been inspected. On the other hand, the heavy metal contamination in all Iraqi cities has been studied using various available literatures. In addition, the study has suggested a linear statistical relationship to correlate the confirmed and death covid-19 cases with different heavy metal concentration. In general, the study has revealed the following:

1. Up to the studied date, the total Iraqi covid-19 confirmed cases per population were 0.004% compared to 0.461% in Spain (the highest rate in the world).
2. Up to the date of this study, Iraq had the lowest rate of total death cases / population of 0.0002% compared with the three top countries in the world whereas Spain had the highest death / population cases of 0.0534%.
3. For the heavy metal contamination, Dohuk city had the highest Cd content of 56.52 µg / g (61% of the total concentration in all Iraqi cities) while Wasit had the highest Cr concentration of 425.2 µg / g (25% of the total concentration in all Iraqi cities).
4. The extreme contents of Cu, Ni, Pb, and Zn are concentrated in Al-Qadisiyah, Al-Sulaimaniyah, Erbil and Baghdad cities with limits of 160 µg / g, 240.9 µg / g, 378 µg / g and 1080 µg / g respectively.
5. In various Iraqi cities, the levels of heavy metal contamination for different chemical elements have exceeded the upper allowable world limits where the maximum rate was for Cd content in Dohuk city that exceeded the allowable upper limit by 30 times.
6. Based on the proposed statistical model, there is a linear positive relationship for both confirmed and death covid-19 cases with different heavy metal contamination with a maximum value of R^2 of 0.97.

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Table 1. The allowable limit for heavy metal concentration in soil µg / g (European Commission Director General ECDGE 2010)

Element	Germany	Netherlands	Sweden	USA	Ireland
Cd	1.0	0.5	0.4	1.9	1.0
Cr	60.0	30.0	60.0	150.0	---
Cu	40.0	40.0	40.0	75.0	50.0
Hg	0.5	0.5	0.3	0.85	1.0
Ni	50.0	15.0	30.0	21.0	30.0
Pb	70.0	40.0	40.0	15.0	50.0
Zn	150.0	100.0	100-150	140.0	150.0

Table 2. Data collection for different chemical elements all over Iraq.

Reference	Element	Concertation (µg / g)	Remarks
Al-Jaberi and Al-Dabbas (2014)	Cobalt (Co)	17.7	• City: Al-Basrah. • No. of samples: 23. • Location: Sediments of coastline. • Method of Testing: Inductively coupled Plasma-Atomic emission spectrometry. • Place of Testing: Uppsala University / Sweden. • Concentration: Maximum tested values.
	Cu	41	
	Ni	119	
	Pb	18	
	Zn	127	
Almayahi et al. (2014)	Cd	0.88	• City: Al-Najaf. • No. of samples: 12. • Location: Different places in the city. • Method of Testing: Flame Atomic Absorption Spectrophotometer. • Place of Testing: University of Kufa / Iraq
	Co	1.31	
	Cr	1.37	
	Pb	3.35	

			• Concentration: Maximum tested values.
Benni (2014)	Co	39	• City: Thi Qar. • No. of samples: 436. • Location: All over the city. • Method of Testing: Atomic Absorption Analysis. • Place of Testing: chemical laboratories / Iraq Geological Survey • Concentration: Maximum tested values.
	Cr	418	
	Cu	144	
	Ni	494	
	Pb	54	
	Uranium (U)	2.66	
	Zn	310	
Othman et al. (2014)	Cd	10.4	• City: Mosul. • No. of samples: 20. • Location: Crowded streets and near generators. • Method of Testing: Atomic Absorption Analysis. • Place of Testing: Mosul University / Iraq • Concentration: Maximum tested values.
	Cu	135	
	(Fe)	455.4	
	Manganese (Mn)	229.6	
	Pb	289.6	
	Silicon (Si)	21.8	

Al-Hamdani et al. (2016)	Cd	0.54	• City: Kirkuk. • No. of samples: 99. • Location: All over the city (one sample / km^2). • Method of Testing: Inductively Coupled Mass Spectrometry. • Place of Testing: Laboratory of Soil Mechanics / Kirkuk Construction Lab / Iraq. • Concentration: Maximum tested values.
	Co	14.426	
	Cr	128.64	
	Cu	76.45	
	Ni	120.37	
	Pb	341.44	
	Zn	229.48	
Mohammed and Abdullah (2016)	Cd	4.31	• City: Baghdad. • No. of samples: 24. • Location: Various places near north of east Baghdad oil field. • Method of Testing: Inductively coupled Plasma-Mass Spectrometry. • Place of Testing: ALS Group Labs. / Spain. • Concentration: Maximum tested values.
	Cr	123	
	Cu	82	
	Ni	196.5	
	Pb	31	
	Zn	1080	

Yousif (2016)	Cd	56.52	• City: Dohuk. • No. of samples: 120. • Location: Places near the pavement edges of five different zones. • Method of Testing: Shimadzu device, model 6401F, Japan. • Place of Testing: Zakho University / Iraq. • Concentration: Maximum tested values.
	Co	56.52	
	Ni	82.7	
	Pb	85.15	
	Zn	83.79	
Abood (2017)	Cr	93	• City: Diyala. • No. of samples: 28. • Location: Different places all over the city. • Method of Testing: X-ray fluorescence. • Place of Testing: University of Diyala / Iraq. Concentration: Maximum tested values.
	Cu	38	
	Fe	16650	
	Ni	121	
	Pb	93	
	Zn	240	
Tawfiq and Ghazi (2017)	Cd	1.10	• City: Misan.
	Cr	86.8	

	Ni	90.1	• No. of samples: 28. • Location: Residential, industrial, commercial and agricultural zones in the city. • Method of Testing: Inductively coupled Plasma-Mass Spectrometry. • Place of Testing: University of Baghdad / Iraq. • Concentration: Maximum tested values.
	Pb	78.7	
Al-Dabbas et al. (2018)	Co	18	• City: Al-Qadisiyah. • No. of samples: 12. • Location: western and eastern zones in the city. • Method of Testing: X-ray diffraction and X-ray fluorescence. • Place of Testing: University of Baghdad / Iraq. • Concentration: Maximum tested values.
	Cu	160	
	Ni	200	
	Pb	110	
	Zn	190	
Sürücü et al. (2018)	Cd	5.01	• City: Al-Sulaimaniyah.
	Co	10.21	

	Cr	300.6	• No. of samples: 120. • Location: Three sections of main roads connecting the city. • Method of Testing: Atomic Absorption Spectrometer Perkin Almer 8800. • Place of Testing: University of Sulaimania / Iraq. • Concentration: Maximum tested values.
	Pb	245	
	Ni	240.9	
Ahmed and Abd-Alhameed (2019)	Cr	74	• City: Erbil. • No. of samples: 41. • Location: Different locations surrounding the steel company in the city. • Method of Testing: X-ray fluorescence. • Place of Testing: Salahaddin University-Erbil / Iraq. • Concentration: Maximum tested values.
	Cu	85.2	
	Fe	6700	
	Ni	10.2	
	Pb	378	
	Zn	220.4	
Hmood et al.	Cd	0.211	• City: Karbala.

(2019)	Pb	11.712	• No. of samples: 12. • Location: Selected schools in the city. • Method of Testing: Atomic Absorption Spectrometer. • Place of Testing: University of Kerbala, Karbala/ Iraq. • Concentration: Maximum tested values.
Khazaal et al. (2019)	Cd	0.201	• City: Al-Anbar. • No. of samples: 100. • Location: Along the center of Al-Habbaniyyah lake in the city. • Method of Testing: Atomic Absorption Spectrometer. • Place of Testing: National Research Council-Canada. • Concentration: Maximum tested values.
	Cr	0.132	
	Fe	0.423	
	Ni	0.095	
	Pb	0.602	

Manea et al. (2019)	As	8.20	• City: Babil. • No. of samples: 13. • Location: Both soil and river sediments in the city. • Method of Testing: Atomic Absorption Spectrometer. • Place of Testing: University of Baghdad / Iraq. Concentration: Maximum tested values.
	Cd	11.5	
	Co	43	
	Cr	31.6	
	Cu	102	
	Fe	3120	
	Mn	74	
	Ni	68	
	Pb	76.5	
	Zn	131	
Al-Dabbas and Abdullah (2020)	Co	32.5	•City: Salah Al-Din. •No. of samples: 10. •Location: Agricultural area in the city. •Method of Testing: X-ray fluorescence. • Place of Testing: University of Brighton / United Kingdom and University of Baghdad / Iraq.
	Cu	55.1	
	Pb	19.8	
	Zn	140.8	

			•Concentration: Maximum tested values.
Al Sharaa et al. (2020)	Cr	47	• City: Al-Muthanna. • No. of samples: 300. • Location: A chemical weapon storage in the city. • Method of Testing: No information. • Place of Testing: University of Technology, Baghdad / Iraq. • Concentration: Maximum tested values.
	Cu	42	
	Ni	49	
	Pb	34	
	Zn	407	
Issa et al. (2020)	Cd	2	• City: Wasit. • No. of samples: 18. • Location: Sediments covering Tigris river in the city. • Method of Testing: X-ray diffraction and X-ray fluorescence. • Place of Testing: University of Baghdad / Iraq.
	Co	25.4	
	Cr	425.2	
	Cu	56.2	
	Mn	1069	
	Molybdenum (Mo)	15.8	
	Ni	226.6	

	Pb	35.2	•Concentration: Maximum tested values.
	Zn	190.3	
Remarks	Various chemical contaminants.	Minimum element content is Ni (0.095) in Al-Anbar city whereas maximum element content is Fe (16500) in Diyala city.	• City: All Iraqi cities. • No. of samples: Range (10-436). • Location: Various locations such as residential, industrial, commercial, agricultural and river sediments. • Method of Testing: Mainly Atomic Absorption Spectrometer and rarely X-ray diffraction and X-ray fluorescence methods. • Concentration: Maximum tested values

Table 3. Statistical model parameters (Eqs. 1, 2 and 3)

Heavy Metal Type	Confirmed Cases Covid-19 (Eq. 1)			Death Cases of Covid-19 (Eq. 2)		
	A	**B**	**R^2**	**A**	**B**	**R^2**
Cd	32.5	0.65	0.84	15.13	0.80	0.83
Cr	17.4	0.96	0.89	9.15	1.09	0.81
Cu	16.2	0.88	0.91	19.3	0.88	0.84
Ni	7.96	0.95	0.91	16.52	0.90	0.86
Pb	28.86	0.70	0.95	27.5	0.73	0.90
Zn	21.16	0.85	0.97	25.06	0.85	0.94

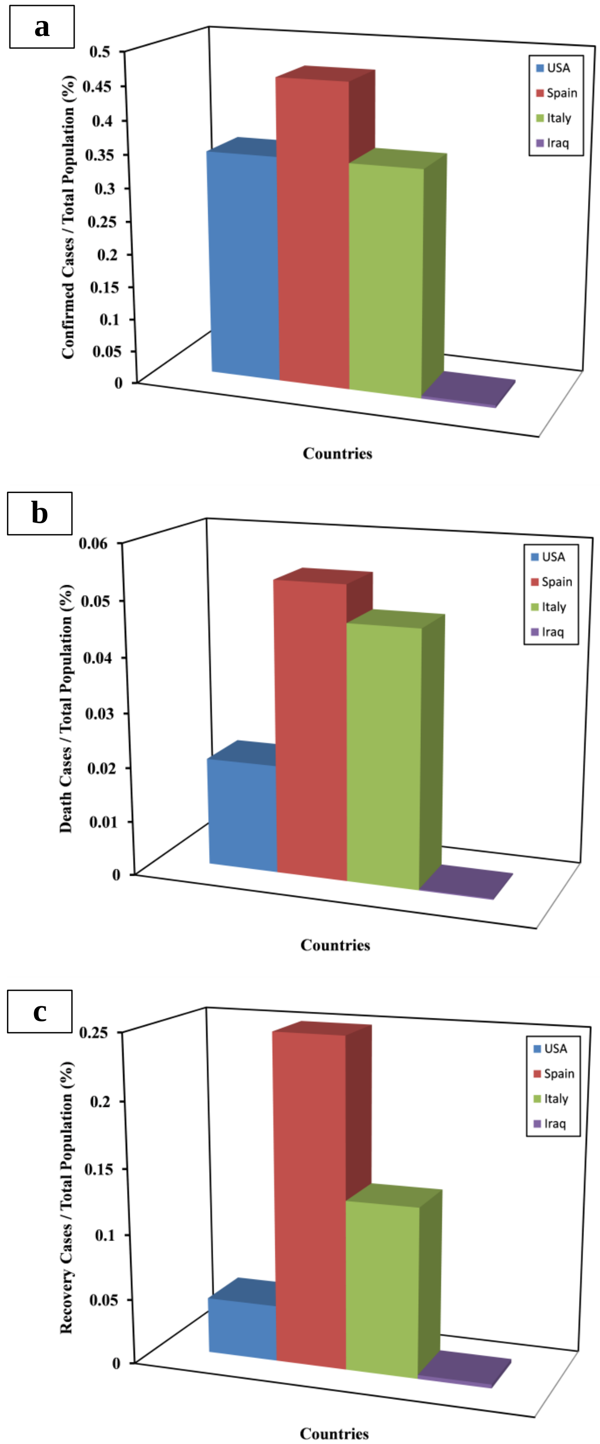


Fig. 1. Comparison between Iraq and three top countries in world for (a) the confirmed cases / total population of covid-19 virus, (b) the death cases / total population of covid-19 virus, and (c) the recovery cases / total population of covid-19 virus .

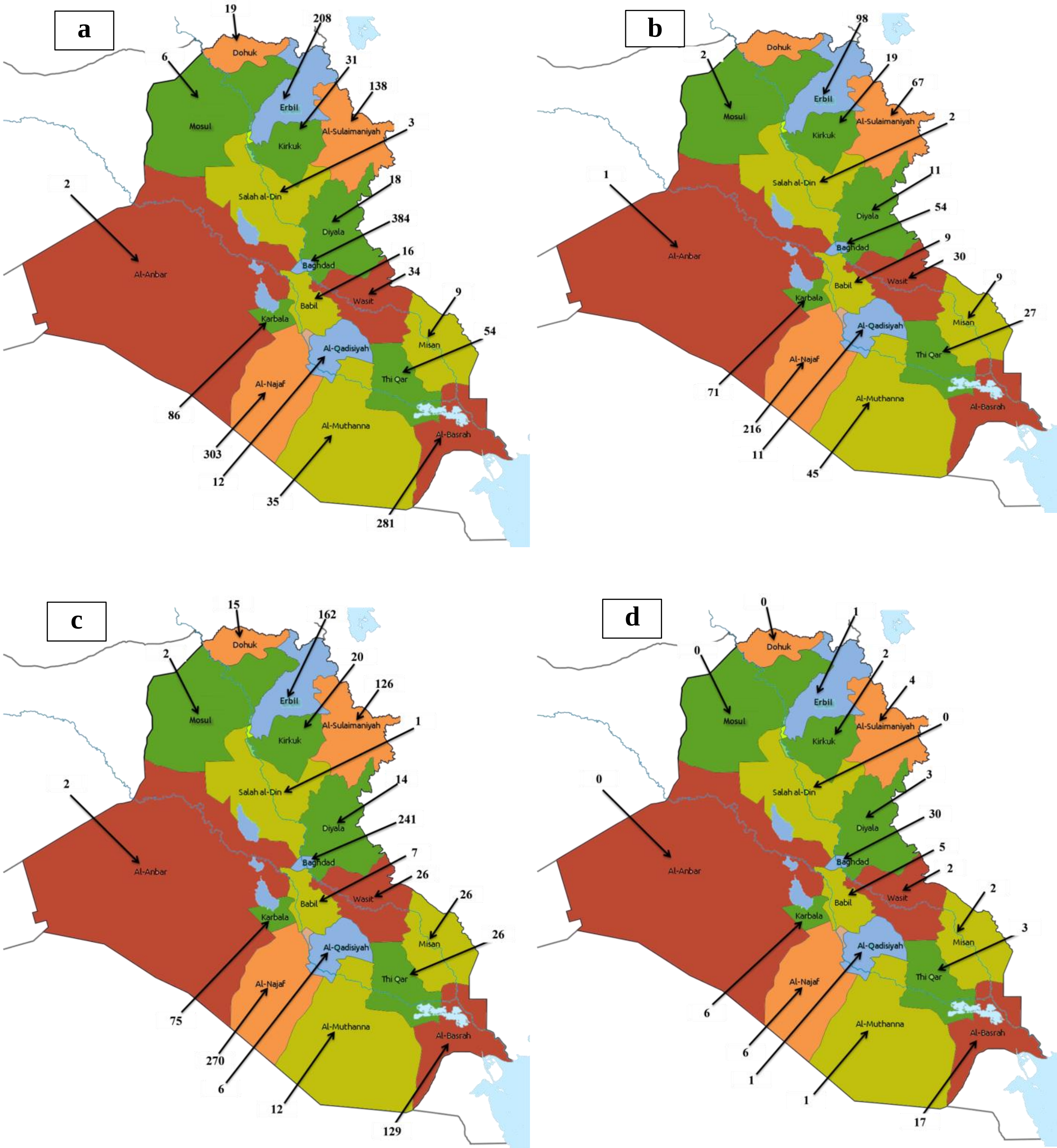


Fig. 2. The map distribution of (a) confirmed covid-19 cases in all Iraqi cities, (b) confirmed covid-19 cases per million of city population in all Iraqi cities, (c) recovered covid-19 cases in all Iraqi cities, and (d) deaths of covid-19 cases in all Iraqi cities .

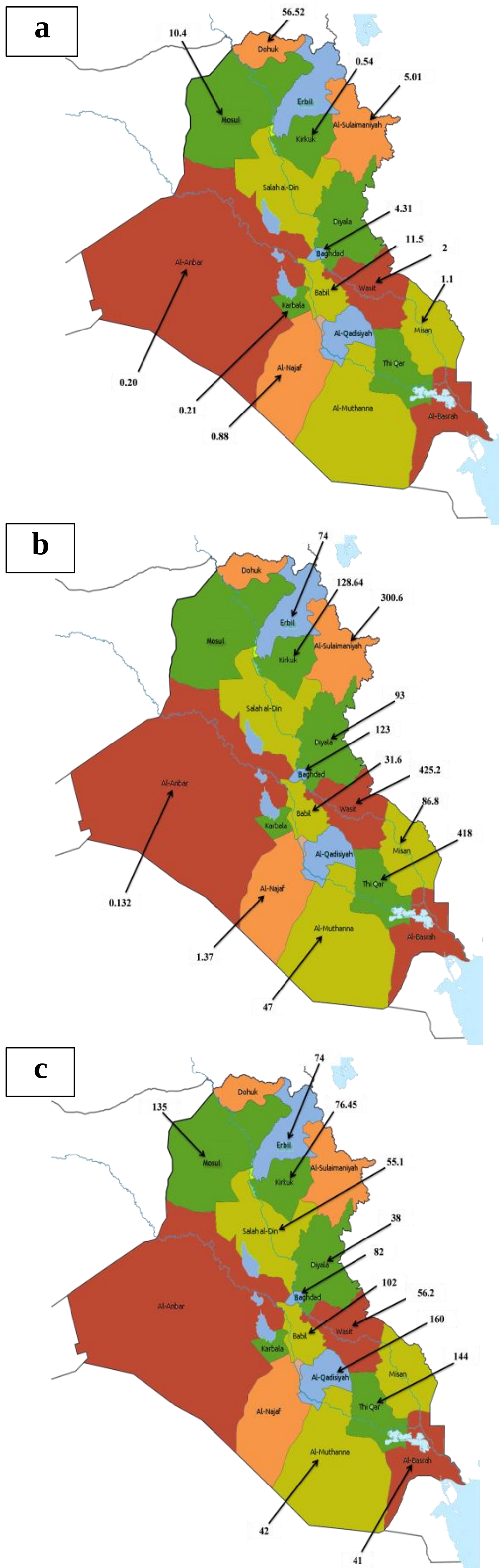


Fig. 3. The map distribution of various chemical elements (µg / g) in different Iraqi cities

(a) Cd, (b) Cr, and (c) Cu.

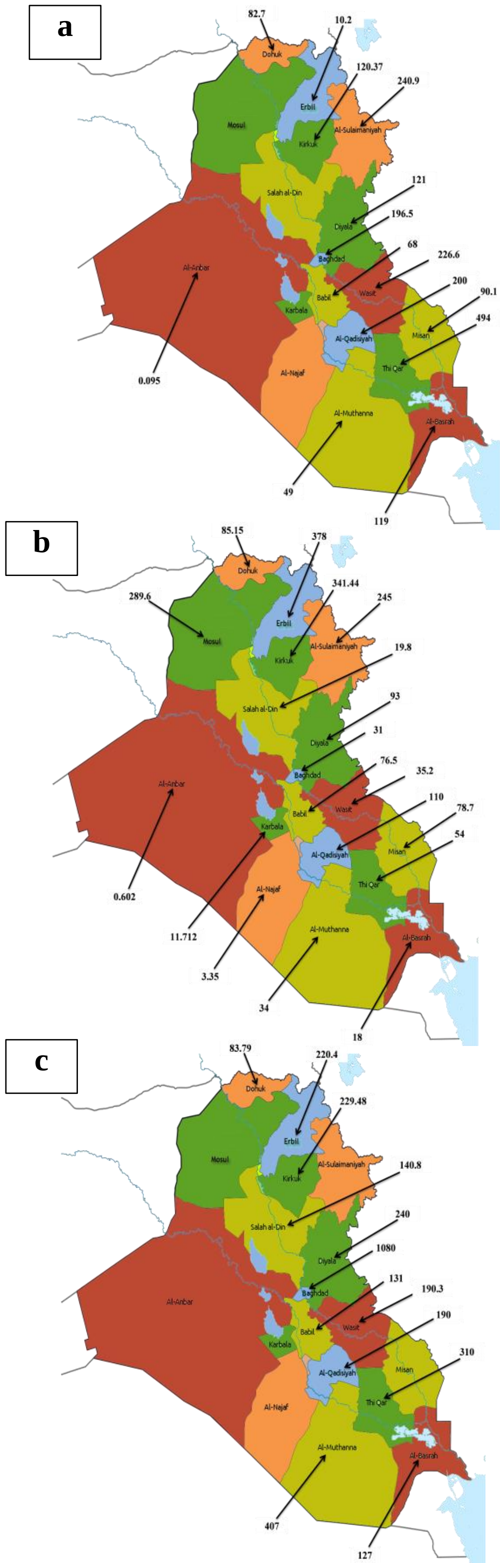
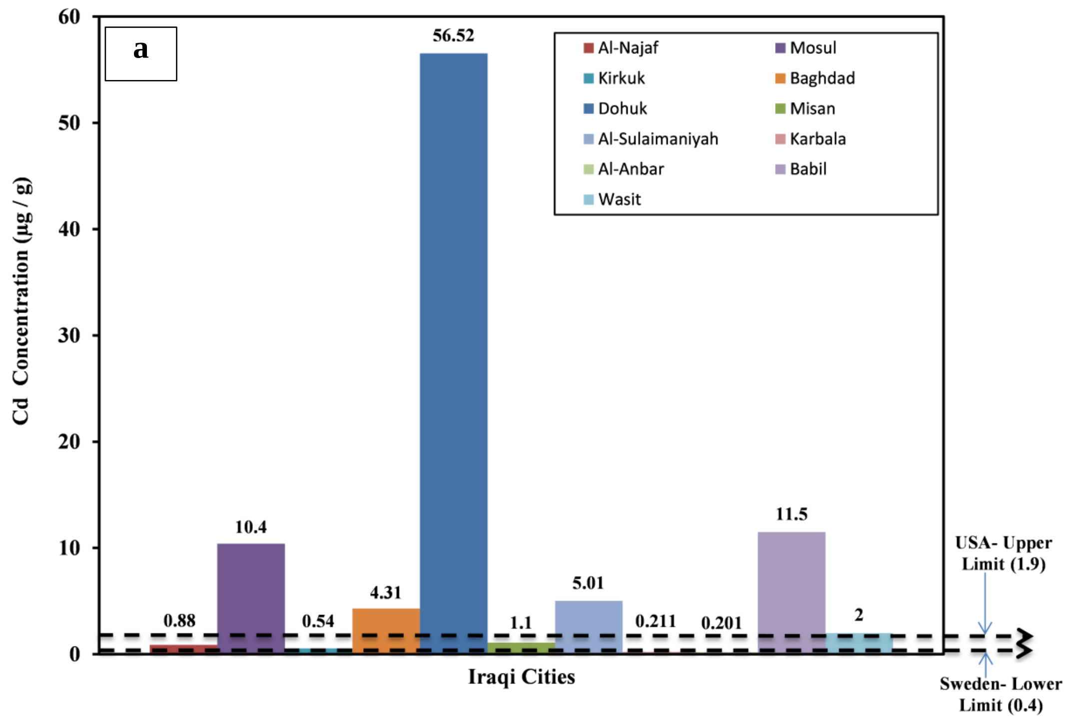


Fig. 4. The map distribution of various chemical elements (μg / g) in different Iraqi cities (a) Ni, (b) Pb, and (c) Zn.



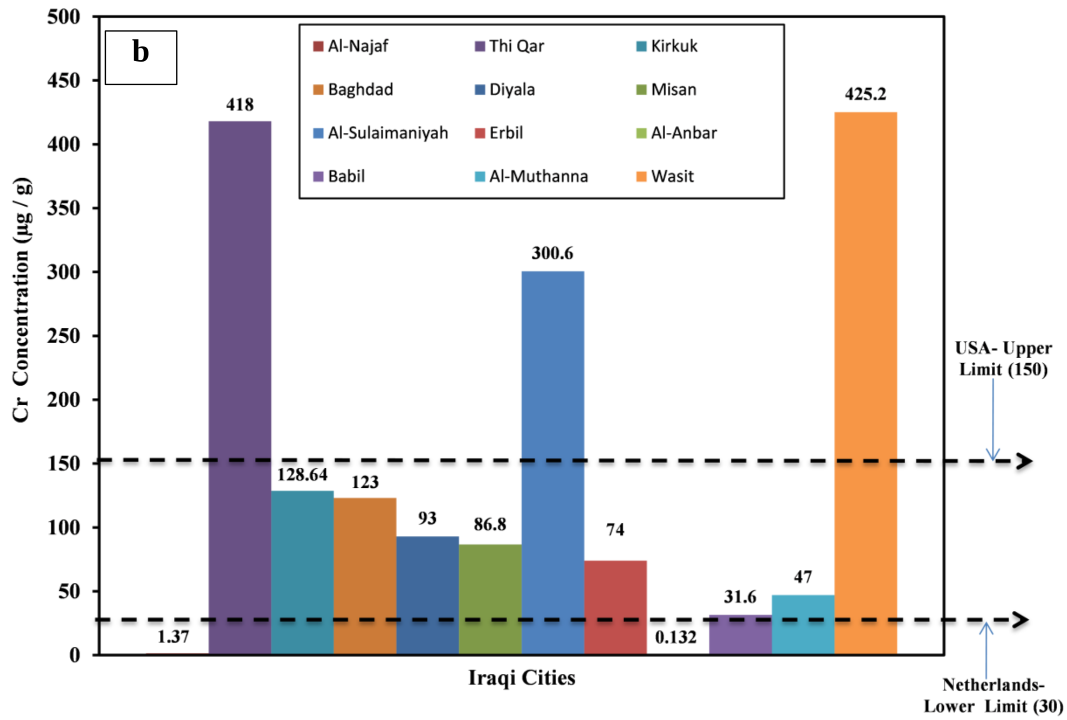
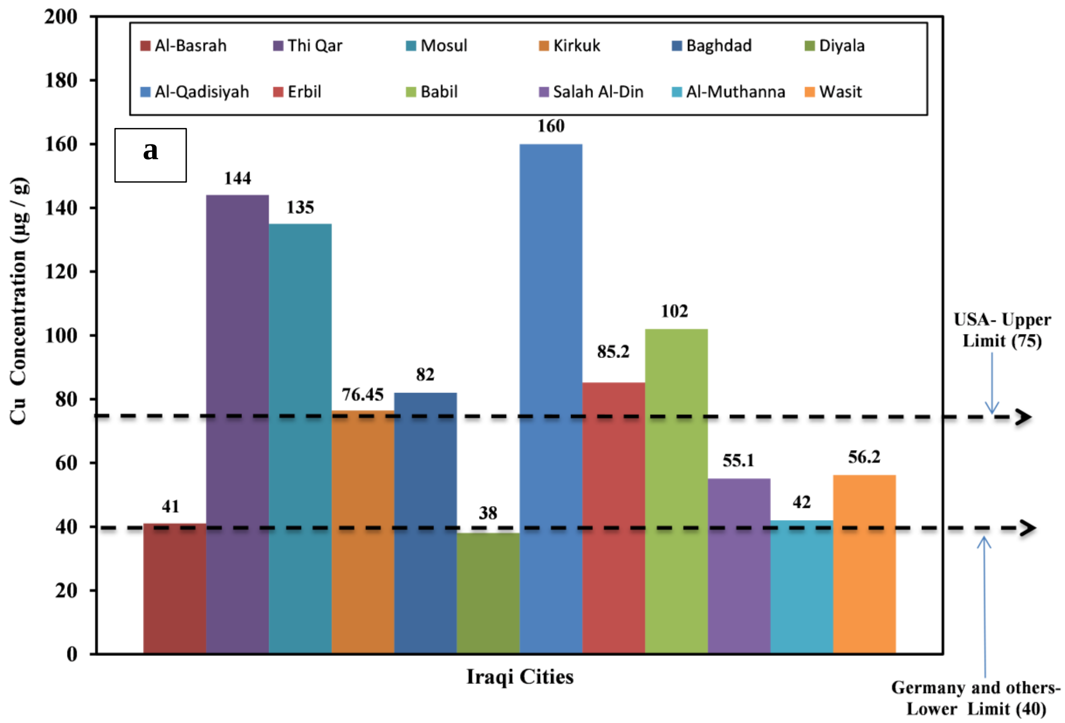


Fig. 5. A bar chart comparison between various chemical element distributions (µg / g) with upper and lower standard limits in several Iraqi cities (a) Cd, and (b) Cr.



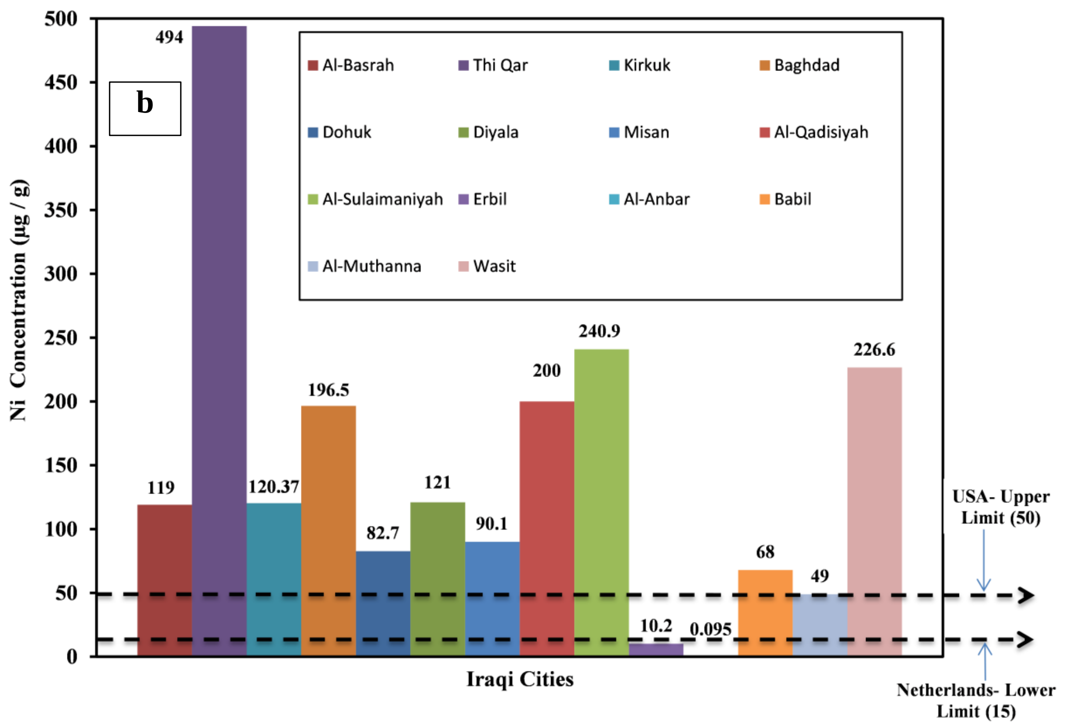


Fig. 6. A bar chart comparison between various chemical element distributions (µg / g) with upper and lower standard limits in several Iraqi cities (a) Cu, and (b) Ni.

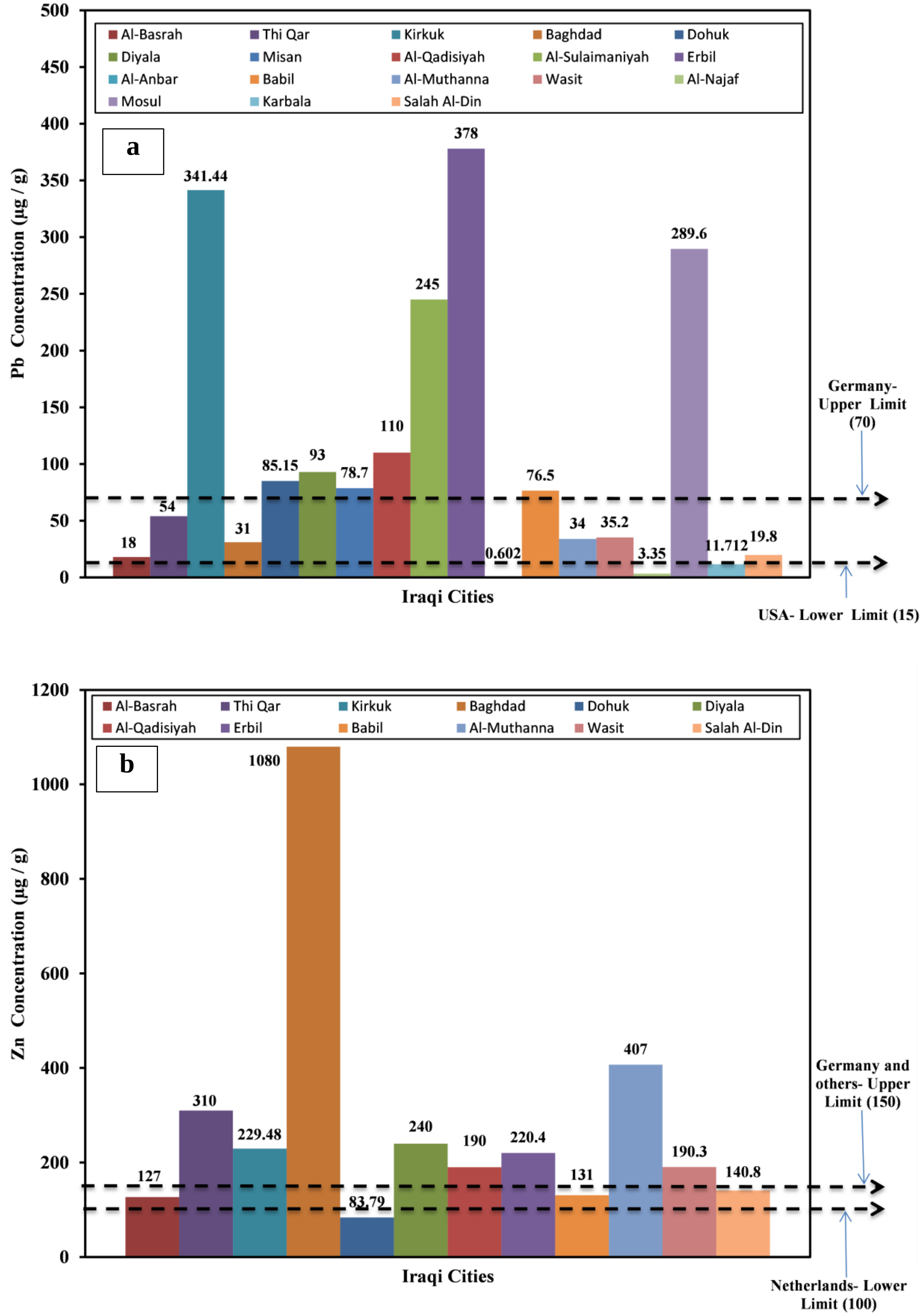


Fig. 7. A bar chart comparison between various chemical element distributions (µg / g) with upper and lower standard limits in several Iraqi cities (a) Pb, and (b) Zn.

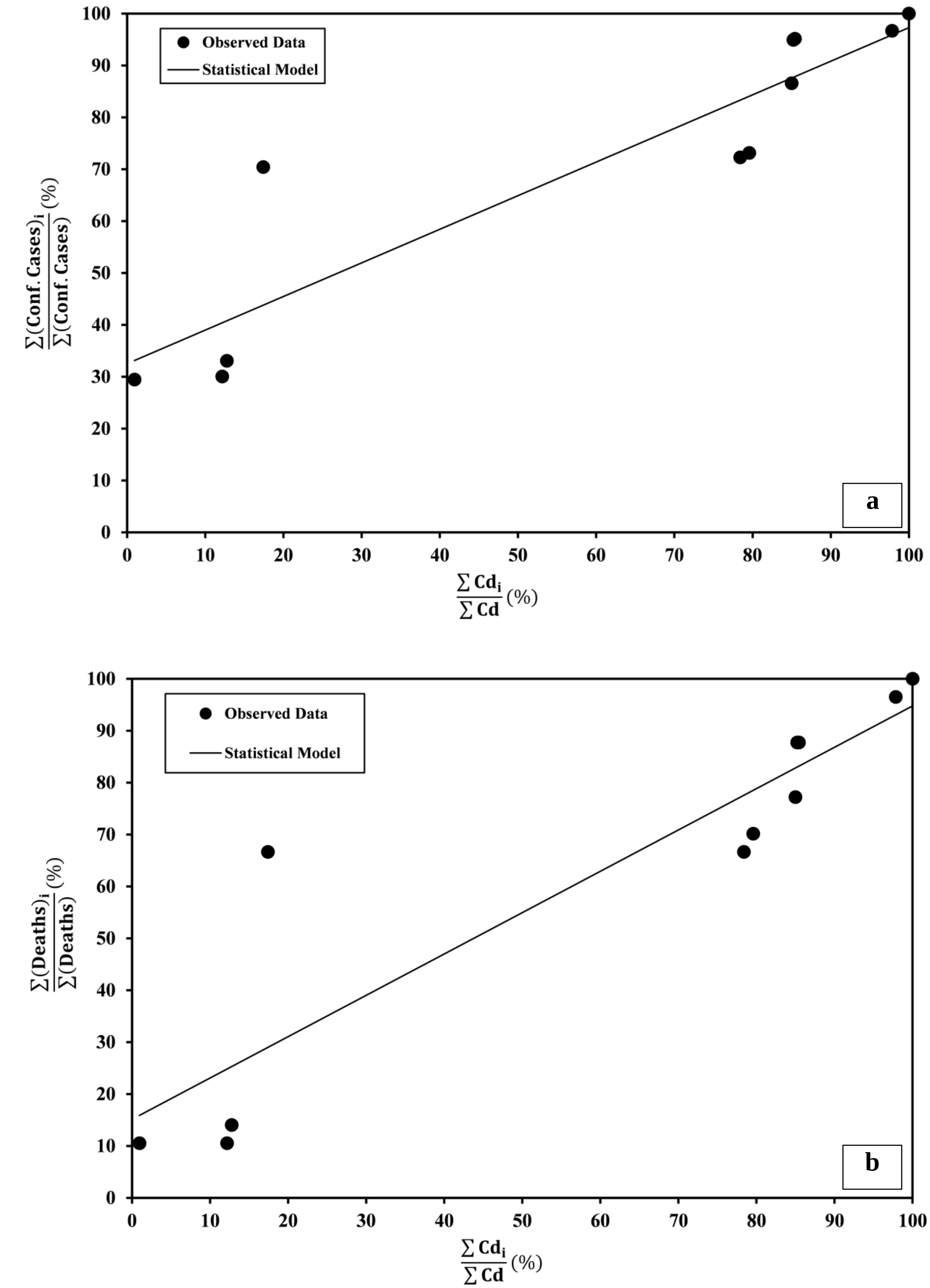
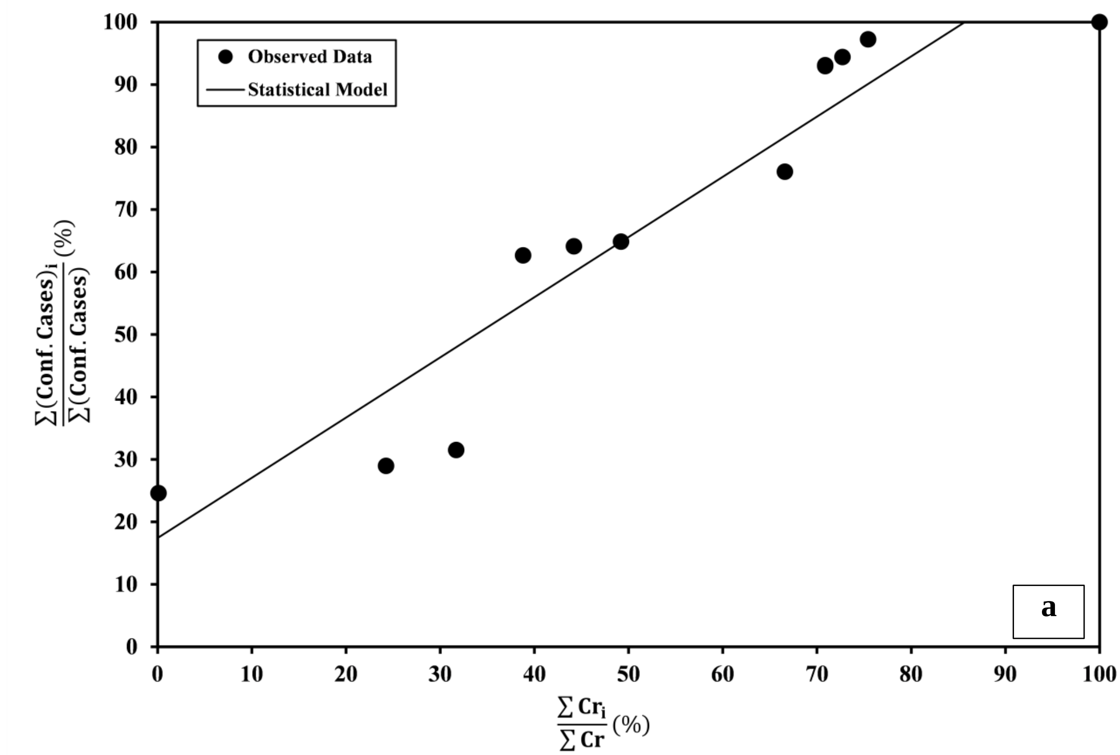


Fig. 8. Hierarchical model prediction for the variation of covid-19 with Cd chemical element for (a) confirmed cases, and (b) death cases.



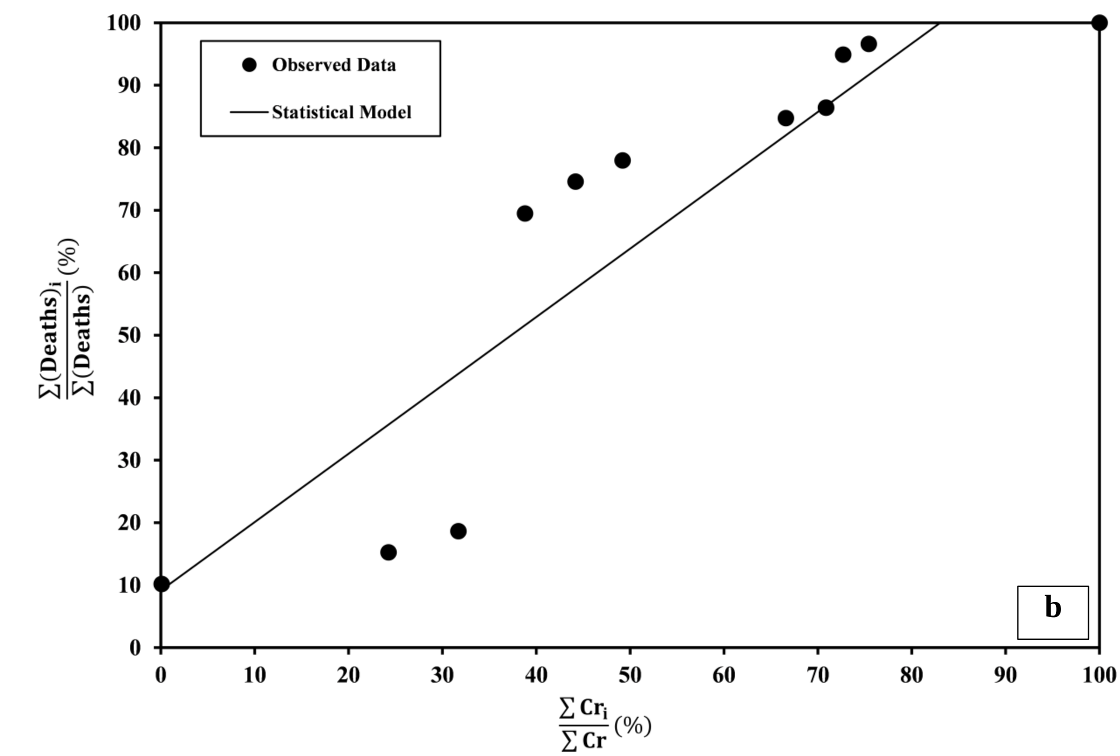


Fig. 9. Hierarchical model prediction for the variation of covid-19 with Cr chemical element for (a) confirmed cases, and (b) death cases.

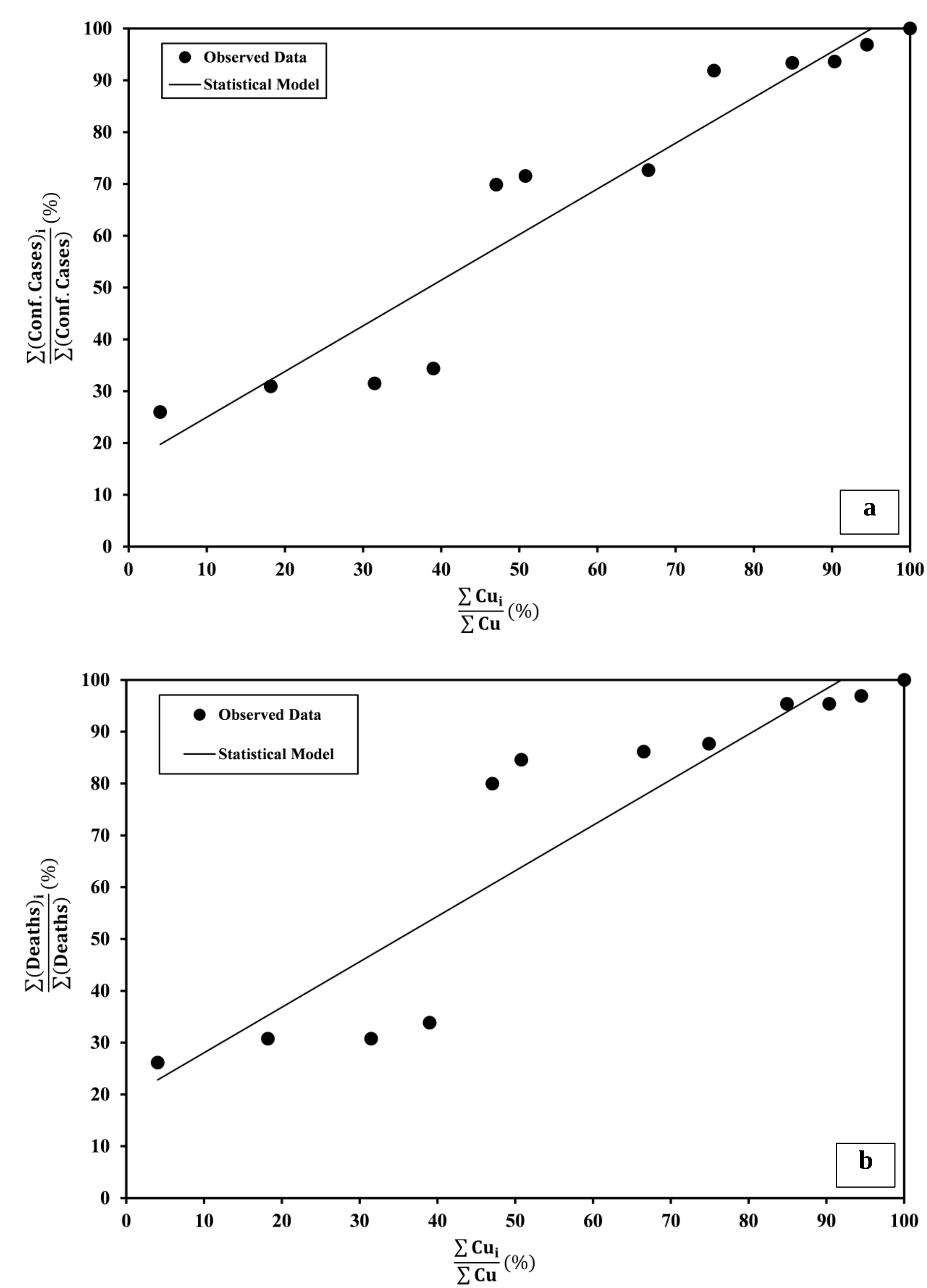


Fig. 10. Hierarchical model prediction for the variation of covid-19 with Cu chemical element for (a) confirmed cases, and (b) death cases.

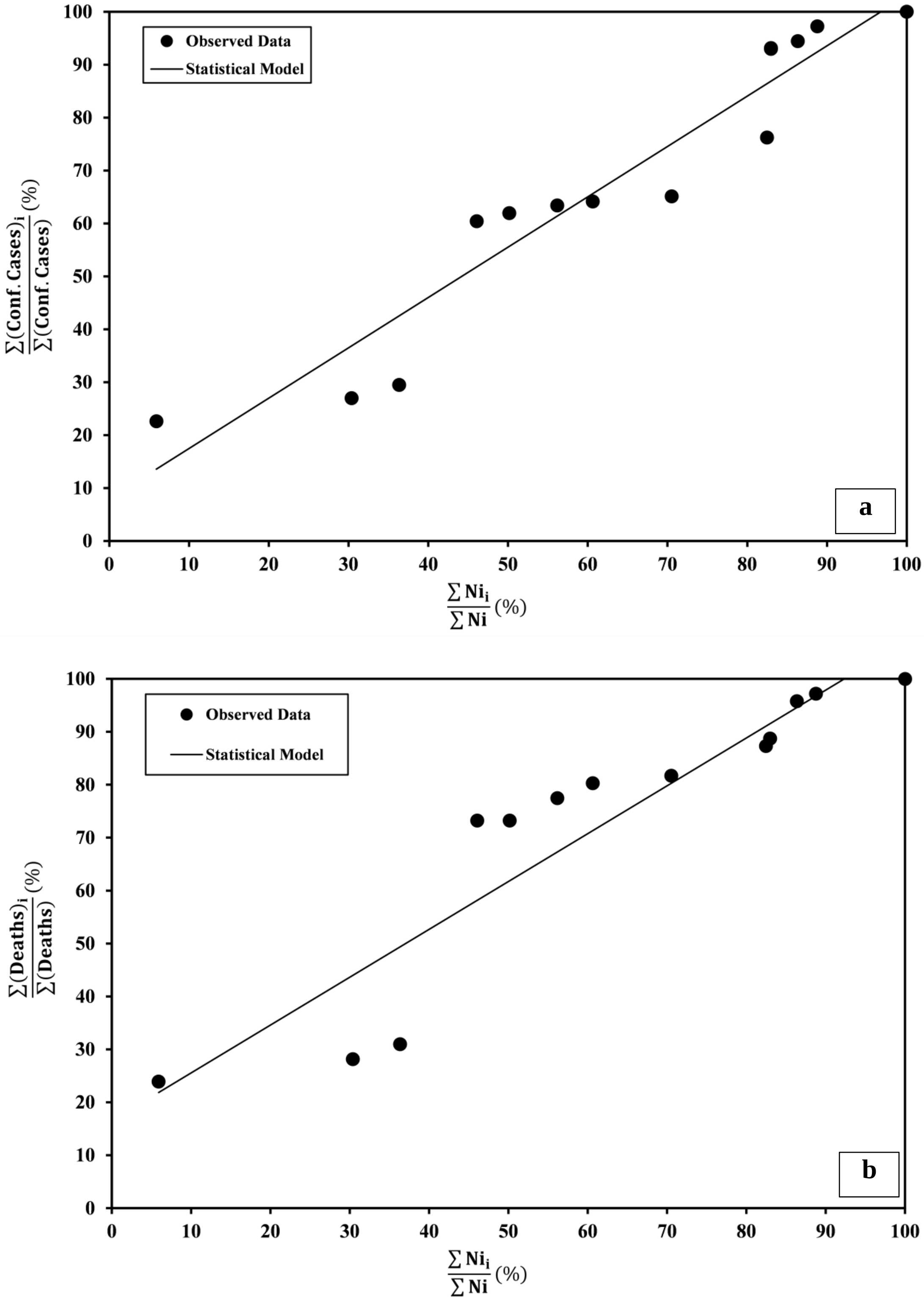
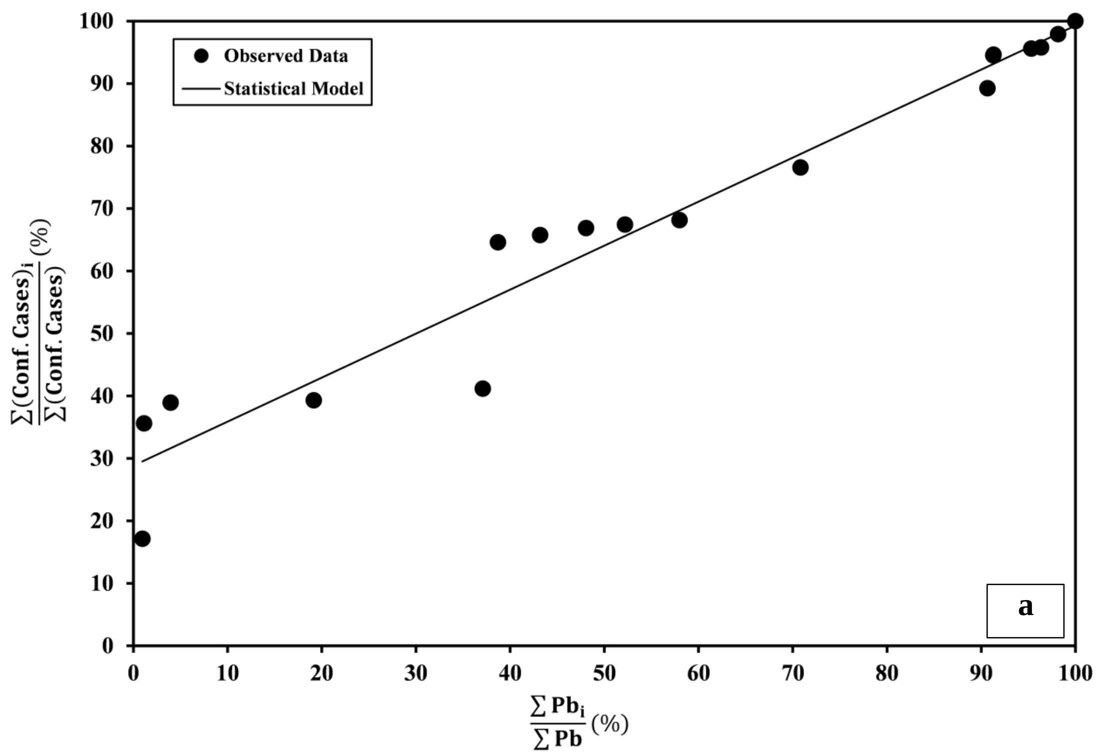


Fig. 11. Hierarchical model prediction for the variation of covid-19 with Ni chemical element for (a) confirmed cases, and (b) death cases.



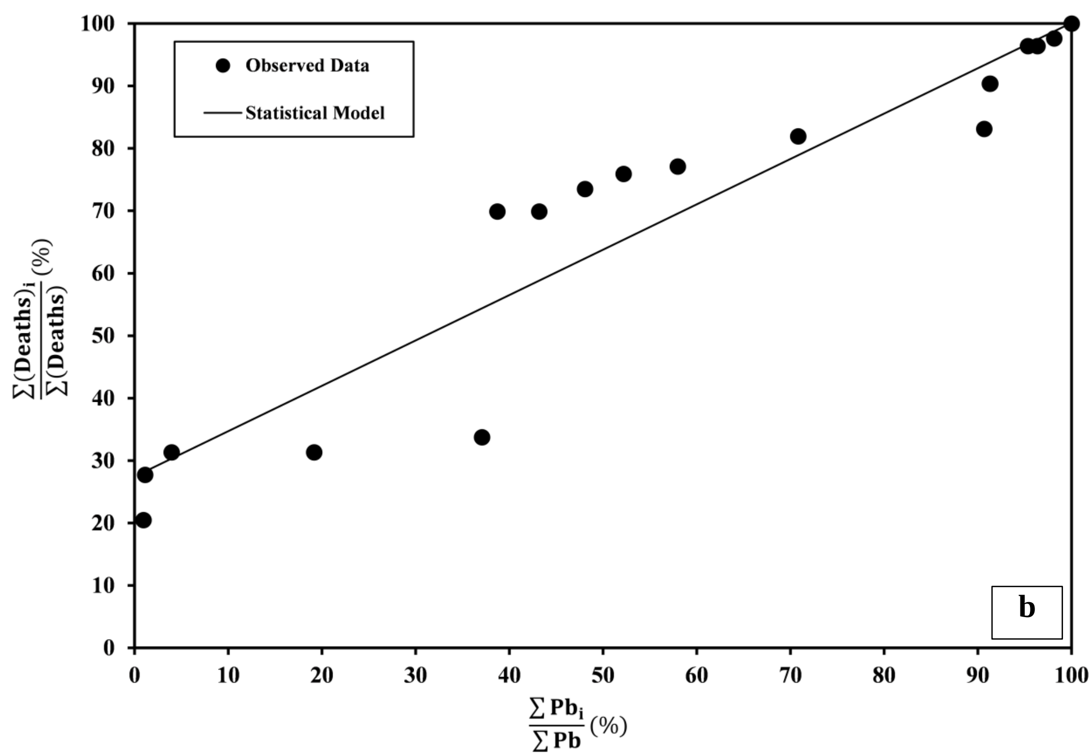


Fig. 12. Hierarchical model prediction for the variation of covid-19 with Pb chemical element for (a) confirmed cases, and (b) death cases.

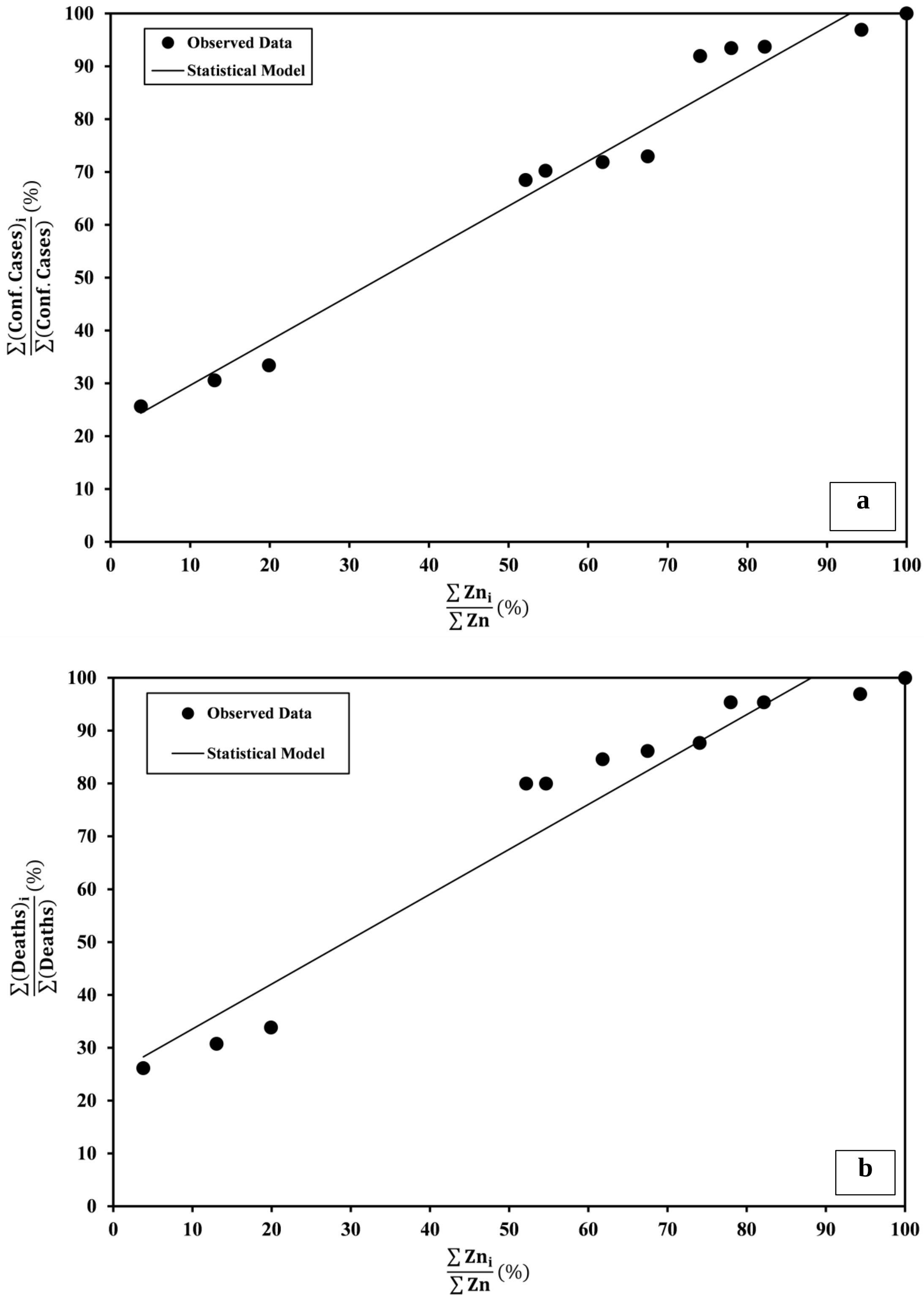


Fig. 13. Hierarchical model prediction for the variation of covid-19 with Zn chemical element for (a) confirmed cases, and (b) death cases.