RISK ASSESSMENT OF HEAVY METALS PRESENT IN SOIL AND WATER ECOSYSTEMS OF LEH

Dissertation submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

IN

BIOTECHNOLOGY

By

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217801

Under the supervision of

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May 2023

Candidate's Declaration

I hereby declare that the work presented in this report entitled **"Risk Assessment of Heavy Metals present in the soil and water ecosystems of Leh"** in complete fulfillment of the requirements for the award of the degree of **Master of Science** in **Biotechnology** submitted to the Department of Biotechnology & Bioinformatics**,** Jaypee University of Information Technology, Waknaghat is an authentic record of my own work carried out over a period from August 2022 to May 2023 under the supervision of **Dr. Sudhir Kumar** , Prof. & Head, Department of Biotechnology and Bioinformatics, Jaypee University of Information Technology, Waknaghat and **Dr. Vijay Kumar Bharti**, Scientist-E (DRDS) & Group Head, Animal Science Division, DRDO-DIHAR.
The matter embodied in the report has not been submitted for the award of any other degree or diploma.

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This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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ACKNOWLEDGEMENT

Firstly, I express my heartiest thanks and gratefulness to almighty God for His divine blessing making it possible to complete the project work completely. This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and their valuable time, assistance & support in the preparation and completion of this study. It is a pleasure to convey my gratitude to them all in my humble acknowledgement.

I am really grateful and wish my profound indebtedness to my Supervisor **Dr. Sudhir Kumar** (Head of department, Department of Biotechnology and Bioinformatics). His endless patience, scholarly guidance, continual encouragement, constant and energetic supervision, constructive criticism, valuable advice, and reading many inferior drafts and correcting them at all stages have made it possible to complete this project. I am truly grateful to my co-guide **Dr. Vijay Kumar Bharti**, Scientist-E (DRDS) & Group Head, Animal Science Division, DRDO-DIHAR, Leh for his guidance, supervision and advice. Deep knowledge & keen interest of my supervisor in the field of "Risk assessment of heavy metals present in soil and water ecosystems of Leh" helped me to carry out this project.

I would like to express my heartiest gratitude towards **Ms. Pooja Thakur** (PhD Scholar, JUIT) for her endless help in every step of the way. I would also generously welcome each one of those individuals who have helped me straightforwardly or in a roundabout way in making this project a win. I am deeply grateful to **Mr. Baleshwar Prasad and Ms. Mamta Mishra** for their immense availability to guide me in this work and knowledge or guidance they provided with along the way. They truly demonstrate what a brilliant and hard-working lab technician can accomplish.

Finally, I must acknowledge with due respect the constant support and patience of my parents.

Poshita Sachdeva

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
Ni	Nickel
Zn	Zinc
Co	Cobalt
Fe	Iron
Cu	Copper
Pb	Lead
Cd	Cadmium
As	Arsenic
Mn	Manganese
Cr	Chromium
Hg	Mercury
AAS	Atomic Absorption Spectrophotometer
LAHDC	Ladakh Autonomous Hill Development Council
ADD	Average Daily Dosage
WHO	World Health Organization
USEPA	US Environmental Protection Agency
DRDO	Defense Research and Development Organization
DRDO-DIHAR	Defense Research and Development Organization- Defense Institute of High-Altitude Research
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
HCL	Hollow Cathode Lamp

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ABSTRACT

This dissertation portrays thorough assessment of the health risks associated with water and soil contamination in Leh, an ecologically sensitive region currently experiencing rapid urbanization and industrialization due to population growth. The study employs Atomic Absorption Spectrometer (AAS) to enumerate the concentration of Co, Cu, Cr, Ni, Fe and Zn, heavy metal contaminants prevalent in the area. By considering both anthropogenic activities and natural processes, the research assesses health risks related to these heavy metals. The findings reveal varying levels of heavy metal contamination across different sampling locations, with Choglam exhibiting particularly high risks of chronic exposure for residents towards Cu, Ni, Co and Fe. The outcomes contribute to the understanding of the environmental degradation in Leh and provide a basis for future remediation strategies aimed at mitigating health risks linked to heavy metal pollution. Then again, the findings also suggest that more research is called for to comprehensively assess long-term impacts of heavy metal contamination on health of the residents of Leh.

Keywords: Leh, Heavy Metals, Risk Assessment, Atomic Absorption Spectrometer, Water, Soil

1. INTRODUCTION

Leh is situated in an area of Ladakh along the north branch of the river Indus at an elevation of 3,500 meters above sea level. It is an environmentally sensitive region of Ladakh and has undergone rapid urbanization and industrialization due to population growth. Up until recently, the region's economy had been based primarily on agricultural land utilization. The urban population of India increased at a rate of 2.95% between the years of 1981 and 2001. Whereas the population of Leh increased at a rate of 5.92% per year throughout the same time period. Leh was discovered to have a significantly greater amount of urbanization (23%). Leh town's population has over tripled during the past 20 years. Due to the construction of infrastructure, there has been a noticeable increase in the degree of metals in the surrounding environment. Their presence poses considerable risks to both human health and the ecosystem, necessitating a comprehensive assessment of their occurrence in water and soil.

The main goal of this dissertation is to evaluate the health risks associated with water and soil samples gathered from Leh by quantifying Cu, Co, Cr, Fe, Ni, and Zn using AAS. By evaluating the potential health risks associated with heavy metal contamination, this research aims to deepen our understanding of the environmental degradation occurring in Leh. The findings will provide a foundation for future mitigation strategies aimed at minimizing the health risks stemming from heavy metal contamination. This study focused on water and soil as crucial pathways through which heavy metals can infiltrate the human body. The reason for selecting water and soil as the primary subjects of investigation was their significance in facilitating the entry of heavy metals into the human system. Exposure of humans and other animals to these heavy metals can be via ingestion, inhalation and dermal contact of which ingestion causes the most impact. Consumption of contaminated water or crops grown soil contaminated with heavy metals can cause accumulation of heavy metal in human tissues, resulting in various health issues, ranging from acute toxicity to chronic diseases with long-term implications resulting in the flow of these heavy metals in food web and in the ecosystems. Due to our position at the pinnacle of the food web, humans are exposed to significant levels of these metals. This results in bio-magnification of heavy metals in the bodies of humans.

In order to assess the possible health risks linked to heavy metal exposure, several parameters will be taken into account, including the estimation of daily intake (EDI) of metals, the evaluation of the target hazard quotient (THQ), the calculation of the hazard index (HI), and the determination of the carcinogenic risk factor (CR). These parameters will provide valuable insights into the non-carcinogenic health risk factors and carcinogenic health risk factor posed by contamination of water and soil of Leh by heavy metals. If heavy metals are found to exceed the regulatory limits for these parameters, the local population of that region can be susceptible to various diseases caused by chronic and long-term exposure to heavy metals such as Bronchitis, Dermatitis (skin irritation), Kidney and Liver damage, Gastrointestinal problems, Bone marrow cancer, Rapid hair loss, Respiration problems, Failure of brain and kidney, Severe anemia, Intestinal irritation, Severe anemia, gastrointestinal damage, Mental retardation, central nervous system damage, Immunotoxic response, neurotoxic response, Genotoxic response, Hepatotoxic response, lungs, throat and stomach cancers, skin irritation, nervous membrane damage.

Finally, this dissertation seeks to systematically evaluate the health risks related to heavy metal contamination in water and soil samples from Leh by means of Atomic Absorption Spectrometer (AAS) for quantification of concentrations of heavy metals. The outcomes of this study will provide valuable insights into the degree of heavy metal contamination and the corresponding health risks faced by the local inhabitants in this high-altitude cold desert area. The findings will contribute to a better understanding of the extent of heavy metal pollution and its potential implications for the well-being of the community residing in this region of Leh

2. REVIEW OF LITERATURE

2.1. Topography of Leh, Ladakh

Leh is situated alongside a northern tributary of the river Indus in the Himalayan region of Ladakh elevated at 3,500 meters above sea level. Up until recently, economy of the area had been centered primarily on agricultural land urbanization. Crop cultivation completely relies on melted water from the glaciers for irrigation due to the extreme aridity. Leh has attracted tourists and migrants from both inside and outside of Ladakh over the past few decades. (Dame J. et al., 2019) The urban population of India increased at a rate of 2.95% between the years of 1981 and 2001. Whereas the population of Leh increased at a rate of 5.92% per year throughout the same time period. Leh was discovered to have a significantly greater amount of urbanization (23%). Leh town's population has over tripled during the past 20 years. (Goodall et al., 2004)

Fig 2.1: Map pointing Leh, Ladakh

Urban planning and governance face significant challenges as a result of rapid urban growth, a lack of resources of water, and risk of natural disasters. (Dame J. et al., 2019)

2.2. Causes of urbanization in Leh, Ladakh

Leh's population tripled between 1981 and 2001 during this time of rapid urban growth, reaching its highest point in 2011 at 30,870 people. Like before, there seems to be considerable seasonal movements in the population in the district capital during the summer, when tourism booms and migrant worker's employment in tourism, agriculture, and construction sectors are in high demand. The number of army personnel and seasonal migrant workers from the countryside who have a second house in Leh are not included in the census figures, thus it is estimated that the overall inhabitants in the urban area is considerably greater. (Dame J. et al., 2019)

A

B

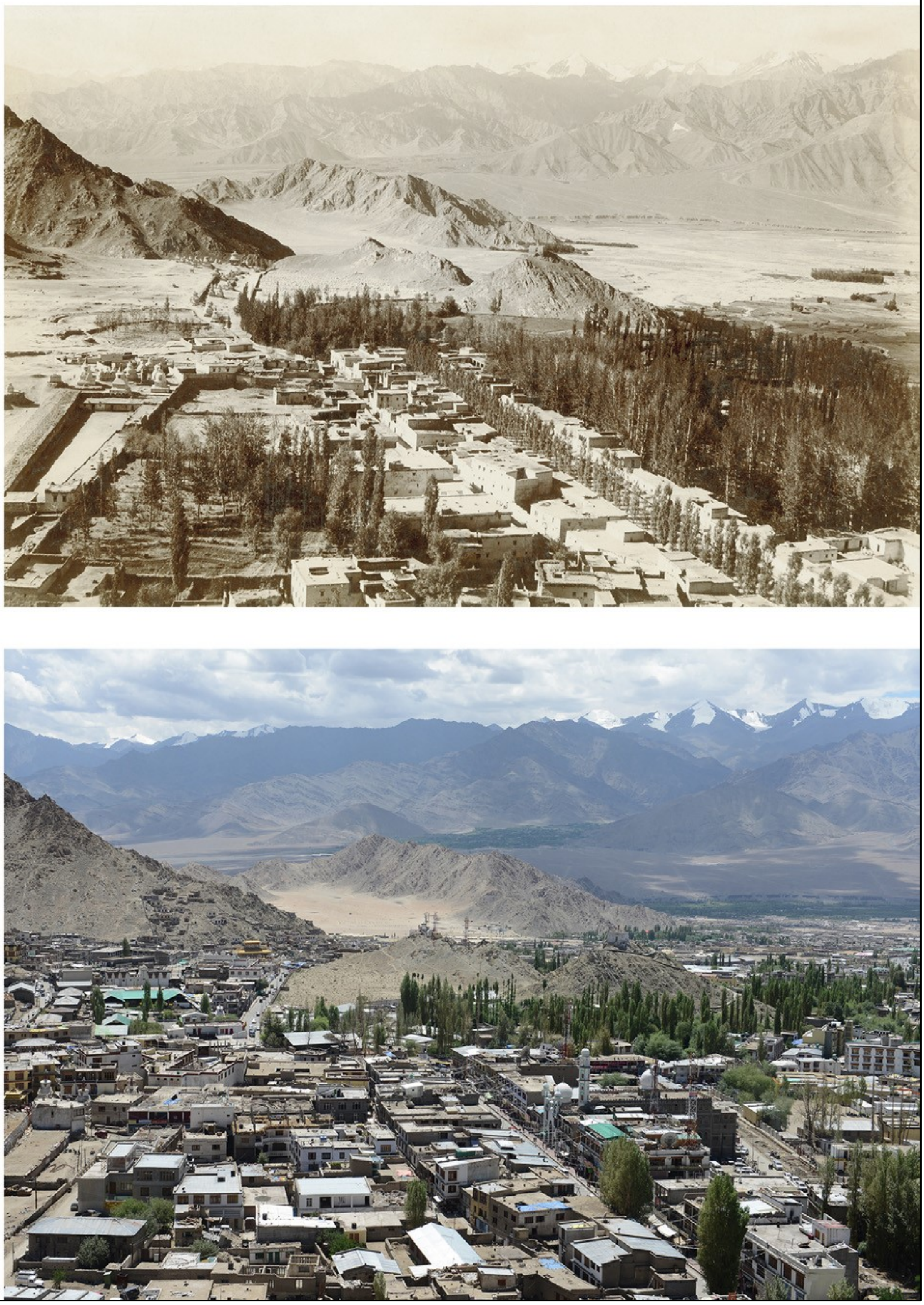

Fig 2.2: photograph taken from Tsemo Hill of Leh (A) 1903-1905; (B) 2013

(Dame J. et al., 2019)

The built-up area has increased four times in size from 36 ha in 1969 to 196 ha in 2017; and 18,660 new buildings have been developed in the same time. This increasing urbanization and building activities are a reflection of the rapid demographic growth. The earliest military outposts, including the airbase and its surroundings in the valley's southern section and a sizable basecamp located near the former Dogra fort in its western tributaries. (Dame J. et al., 2019) Despite being a geographically isolated region, the Leh Ladakh area in India is susceptible to various potential sources of heavy metal pollution. These sources include activities such as arsenic mining, unregulated waste disposal, and the application of pesticides and fertilizers in agricultural practices. These factors contribute to the presence of heavy metals in the region and pose a significant environmental concern. Pesticides and fertilizers often contain a range of metals that contribute to plant health. Copper, zinc, manganese, iron, and boron are commonly found in these products. Copper-based compounds like copper sulfate, as well as zinc sulfate and zinc oxide, are employed as agents to combat fungi and bacteria. Manganese acts as a micronutrient, supporting plant growth, while iron chelates address iron deficiencies. Boron, another micronutrient, aids in plant development. These metals play essential roles in agricultural applications, where they are used in different forms to enhance plant well-being. (Marschner H., 2012)

There is a scarcity of research conducted on the heavy metal content in soil and water within the Leh Ladakh region. However, available data indicate that certain areas may face potential contamination risks. For instance, a study carried out by Giri A. et al in 2021, focused on the Indus River basin that flows through Leh Ladakh. The study discovered elevated levels of As, Cd, and Pb in vegetables, which can pose long-term health hazards if consumed by humans.

A separate investigation involving soil samples from various regions in Leh Ladakh revealed heightened concentrations of Pb, Cd, and Cr in certain areas, potentially attributed to the application of pesticides and fertilizers in agricultural practices. The investigation also noted that high-altitude conditions in the region can exacerbate the effects of heavy metal exposure on human and animal health. (Gupta R. et al., 2017) By 2003, new residential and administrative settlement areas had been built, dramatically raising the number of structures to over 11,800. Large tracts of desert territory have been transformed into concrete environments along Leh's eastern rim. Additionally, completely new quarters, a majority of which are military barracks, have been built in south-eastern and western parts of the nullah.

(Goodall, 2004) While the majority of newer quarters exhibit conventional and ordered layouts, a few, including the Tibetan refugee community in the valley's southmost region, exhibit haphazard constructions. The proportion of farmland loss climbed from 1% in 1969 to 5% in 2003, and 8% by 2017. (Dame J. et al., 2019)

Because the road infrastructure has been expanded further, access to the majority of the town's homes is possible at the expense of dividing up fertile grounds. Buildings like hotels and dining establishments that cater to the tourism industry are frequently built on agricultural property. Numerous new, finer hotels have opened in response to the increase in domestic travelers, and some already-existing hotels have undergone renovations and expansions. (Dame J. et al., 2019)

2.2.1. Three dominant pillars of urban development in this region:

2.2.1.1. An administrative and infrastructural center

Infrastructure of regional significance are accessible to both temporary and long-term migrants in Leh. With a main bus terminal and the sole civilian airfield in the area, it serves as the region's transport hub. In contrast to rural settlements, its bazaars provide a vast variety of goods and services. The public general hospital and private doctors are among the town's top-notch medical services. Similar to how the accessibility of educational establishments has increased recently, respondents usually identify this as a factor in their decision to move to Leh. (Dame J. et al., 2019). Infrastructure such as a bus terminal and an airfield led to an increase in transport vehicles and dump of these transport vehicles when they become junk. Hospitals consist of all types of machines like X-Ray, MRI, etc. that lead to an increase in metal content when these machines are discarded and chemicals containing heavy metals are discharged into water sources and soil.

2.2.1.2. Expansion of the tourism and recreation industry

Ladakh remained inaccessible to outsiders because of its delicate geostrategic location until 1974. The Indian government started to relax travel restraints to encourage provincial financial expansion and stop the massive exodus of the people of Ladakh to mainland. Ladakh has been a well-liked destination for tourists in modern times because of its rich cultural history and beautiful scenery. In 2003, there were 28,400 visitors; this number rose to 79,100 in 2010, and reached 323,590 in 2018. This recent tourism surge is mostly attributable to a sharp rise in domestic tourists. Leh offers a variety of facilities and services for the travel industry as the starting point for hiking and cultural visits to Ladakh. About 30 hotels and guesthouses operated in the area in 1974; this number rose to nearly 190 in 2005; and then to about 650 in 2015. Labor migrants are drawn to the growing tourism industry, mostly from Nepal as well as the lowlands of India. (Dame J. et al., 2019) This exponential increase in tourism has in turn increased the vehicular transportation and the need to accommodate these tourists in hotels. The exhaust from vehicles, the urbanization and construction of more buildings for these tourists and for the economy of Ladakh to grow has put a pressure on the environment. There is a drastic need for more water and food and Ladakh being a cold desert has limited land to cultivate crops thus more fertilizers are being used which elevates the degree of metals and other chemicals in water and soil of the region. Digging of lands has for construction has led to accessibility to metal ores and the leaching of these metals into soil and water bodies. Producing more electricity is required for these tourists and the ever-increasing demand is met by Leh Diesel Power Station, a diesel operated power plant that produces electricity continuously.

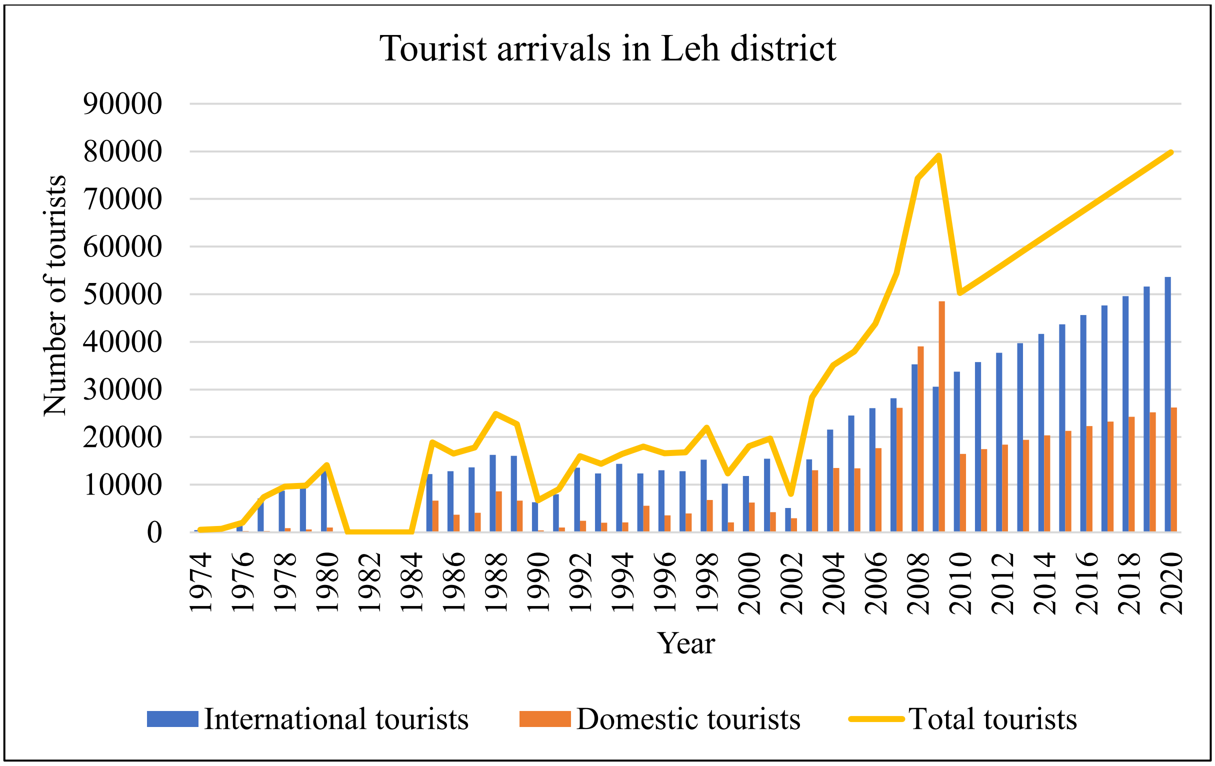

Fig 2.3: Tourist arrivals in Ladakh between 1974 and 2020 (Pelliciardi V., 2010)

2.2.1.3. Spread of urban lifestyle

The area's exposure to international tourists and decreasing dependence on farming have caused urban lifestyle tendencies to spread throughout the area. The socioeconomic changes and progress that are driving rural-to-urban migration are ideal for lively conversations among the people, Nonprofits, and tourists/scientists. With a surge in tourism from other Indian cities or Ladakhi students who frequently pursued studies in metropolitan hubs, social trends among the emerging urban elite are becoming apparent. (Dame J. et al., 2019) This rural-to-urban shift in lifestyle has initiated a rise in schools and colleges as well as jobs thus increasing the number of people in Ladakh who would otherwise go to other states of India to study or find jobs. The increase in population of the region due to this urban lifestyle has demanded an increase in basic necessities like food, clean water, housing and transportation. Fulfilling these basic necessities for the exponentially growing population has spread heavy metals in water and of the region due to excessive use of fertilizers and pesticides for farming on the small area of land available for farming and the inadequate disposal of the waste which is created by small industries as well as the risen population has contributed to this heavy metal pollution.

2.3. Increase in Heavy metal concentration due to urbanization

The rise in population in Leh has resulted in urbanization and a substantial increase in construction projects such as buildings, roads, and transportation infrastructure. Consequently, this construction boom has contributed to a rise in heavy metal content in the soil and water of Leh. Surface and deep soil samples indicate significantly elevated levels of heavy metals, especially Pb and Cd, reaching severely contaminated levels due to construction activities. The pollution of heavy metals, including Ni, Cd, and Pb, in water, caused by vehicle emissions discharged during motor transportation and the development of urban areas and roads, is comparable to the drinking water quality criteria set by WHO. (Xiao R. et al., 2012)

Urbanization has also developed a need for more electricity. This need is compensated for by rigorous operation of the Leh Diesel Power Station which is a diesel operated power plant that along with producing electricity generates a tremendous amount of waste that consists of high quantities of Ni, Co, S, V, Oxides of Nitrogen, Sulphur Dioxide, Particulate matter, etc. Urbanization has led to a growth in the economy of Leh and the reason along with tourism has been small and medium sized industries. One such industry is mining of arsenic from its ore which is present in abundance in Ladakh. Arsenic mining leads to mine tailings that leach into soil and water causing serious arsenic pollution in the region. Cu, Pb, Al, Zn, Fe, Ca also have been severely leached into soil and water from their ores of chalcopyrite, galena, bauxite, pyrite, hematite, magnetite, limestone, etc. due to immense construction of buildings, roads, airports, bus terminals, etc. The discharge of industrial effluents and the generation of waste resulting from human activities have substantially amplified the levels of Cd and Pb in the soil and water of the area.

2.4. Various heavy metals that lead to contamination and their permissible limits

Porphyrin molecules, comprising of cytochromes, hemes, hematin, ferrichrome, and leghemolobin, contain iron as a structural component. These molecules are involved in oxidation-reduction reactions that take place during respiration and photosynthesis. Up to

75% of cellular iron is linked to chloroplasts, while up to 90% of iron in leaves is linked to lipoproteins from the mitochondrial and chloroplast membranes (Havlin et al., 2010). The chloroplasts of quickly growing leaves are where a large quantity of iron is concentrated (Marschner, 1995). Iron is present in soil within a range of 7,000-500,000 mg/kg, as reported by Fageria et al. in 2002. In soil, iron is primarily found as Fe (III) (ferric) and is insoluble. The soluble inorganic iron comprises a combination of these forms along with Fe^{3+} ions. Ferric ions readily undergo hydrolysis, resulting in the formation of $Fe(OH)_2^+$, $Fe(OH)_3$, and $Fe(OH)_4^-$. (Romheld & Marschner, 1986).

While sedimentary rocks like limestone, sandstone, and shale have concentrations of 20, 16, and 95 ppm of zinc (Turekian & Wedepohl, 1961), granitic and basaltic igneous rocks have an average concentration of 70, 40, and 100 ppm of zinc, respectively (Taylor, 1964). Total Zn levels in conventional soils are typically given in the range of 10-300 ppm, and an average of 50 ppm (Vinogradov, 1959).

Main form of cobalt in soil solution is Co^{2+}, albeit the total amount of cobalt in soil solution will be minimal (McBride, 1994). Cobalt is found in soil as Co^{2+}, Co^{3+}, and likely as $Co(OH)_3^-$ (Kabata-Pendias & Pendias, 1992). Premised on geological and soil data, the level of accessible Co in soil can be approximated (Kabata-Pendias & Pendias, 1992). Although the biological function of Co is not fully understood, it is nevertheless thought to be necessary for plants in small amounts.

The biological activities of arsenic, which is present in most plants, have not been established (Kabata-Pendias and Pendias, 1992). The threshold level for the plant is 10 ppm; leaf concentrations of 5-220 ppm on a dry matter basis can be detrimental to plants (Eduardo et al., 2010; Alvarenga, 2006). Consuming soil can cause toxicity in animals and lead to an accumulation of As in the animal's organs, which could provide a health concern to people if the organs or meat are consumed.

According to Kabata-Pendias and Pendias (1992), Cd is phototoxic at levels of 5-30 ppm in leaves on a dry matter basis. However, the average threshold limit for plants is 1 ppm

(Eduardo et al. (2010); Alvarenga (2006)). Without causing any harm to the plant, cadmium can build up to subtoxic levels in edible plant parts (Alloway, 1990). When consumed by humans, cadmium poses a risk because it accumulates quickly in the kidneys and other organs of livestock and other animals. If Cd replaces Zn in enzymes, it can accumulate in animals and lead to illnesses; indications of harmfulness involve renal weakening, emphysema, gastrointestinal disfunctions, and anaemia (Lagerwerff, 1972).

Although there is some evidence that Cr^{3+} can stimulate plant growth, there is no proof that Cr is necessary for plants (McGrath and Smith, 1990). According to Scott (1972), mammals need Cr^{3+} to get rid of extra glucose. Deficiencies have been discovered in both humans and animals. It has also been noted that Cr^{6+} is hazardous to both animals and plants (Kabata-Pendias and Pendias, 1992).

Lead in non-essential trace metal for plants, animals and humans. Lead is extremely lethal to animals at a concentration of 30 ppm [FAO, 1992] and directs to proficiency problems in red blood cell synthesis.

Nickel accumulates in leaves and seeds and is easily transported throughout plants (Kabata-Pendias and Pendias, 1992). Animals need nickel, and there have been some confirmed cases of deficiency. It might be necessary for maintaining human health (McGrath and Smith, 1990). Ni deficiency is rare to happen naturally in either plants or animals.

Table 2.1: Standard concentrations of heavy metals in soil (USEPA and WHO).

HEAVY METALS (mg/Kg)	USEPA STANDARD (mg/ Kg)	WHO STANDARD (mg/ Kg)	REFERENCE
Fe	35000	430000	WHO (1996)
Zn	120	300	USEPA (2006)
Hg	0.1	0.3	USEPA (1997)
Cu	63	150	USEPA (2005)
Cd	0.4	3	USEPA (2006)
Cr	120	150	USEPA (2011)
Pb	400	300	USEPA (2001)
Ni	420	70	USEPA (2017)
Co	50	10	USEPA (2000)

Table 2.2: Heavy metal standard concentrations in water (WHO and USEPA)

HEAVY METALS	WHO STANDARDS (mg/L) (2017)	USEPA (mg/L) (2020)
Cd	0.01	0.005
Cu	2.0	1.3
Pb	0.1	0.015
Zn	3.0	5.0
Mn	0.4	0.05
Ni	0.02	0.1
Cr	0.05	0.1
Co	0.05	-
Fe	0.3	0.3
Hg	0.001	0.002
As	0.01	0.01

2.5. Effects of Heavy metals on human health

Results from Adimalla N.,2020 study reported that dermal contact and inhalation of heavy metals that were present in soil of urban region didn't show any noteworthy risk to health of children as well as adults whereas exposure to heavy metals via ingestion showed significantly higher values. Consumption rates for Cr and As in children were higher by seven times than that in adults and has a much higher contribution of 39.76 and 49.82, respectively posing severe health risk in the urban population. Contribution to severe health risk of Cr is about 40 times more than any other heavy metal and that of As is about 47.17% higher in adults and 45.99% higher in children than any other heavy metal. Whereas Cu, Zn, Pb and Ni have no potential heal risk to adults or children.

Pb pollution in soil of 32 urban Indian cities have shown no significant carcinogenic health risk whereas Cr and As have a potential for risk of cancer to occupants of the area. (Adimalla N., 2020) Metal exposure has received a lot of attention since heavy metals are harmful to human health even at low amounts. (Miclean M. et al., 2019)

Excessive intake of copper can damage the liver and kidneys, impede growth and reproduction, and potentially be fatal. Prolonged ingestion to copper dust can cause irritation to eyes, nose, and mouth, along with symptoms such as headaches, nausea, and diarrhoea. Chromium poisoning can result in lung cancer, digestive disorders, ulcers, seizures, kidney and liver damage, dermatitis, asthma, and reproductive toxicity. Cadmium can penetrate the placenta during pregnancy, be absorbed through the digestive tract, and harm DNA and membranes. Renal failure and changes in bone tissue's calcium metabolism are both brought on by cadmium. (Yasotha A. et al., 2020).

The connection between exposure to arsenic and human cancers is noteworthy since arsenic can be found in tumor tissue. Examples of the link between arsenic and cancer include studies that demonstrate a connection between exposure to arsenic and the emergence of bladder, lung, and skin cancers. Another encouraging link between arsenic exposure and the occurrence of human cancers was explored in relation to mortality rates in patients with a variety of tumors, including colon, stomach, kidney, lung, and nasopharyngeal cancers. Notably, there is a clear association between chronically low arsenic exposure and the formation of non-lymphoma Hodgkin's and pancreatic cancer based on epidemiological data from multiple studies. (Gallicchio V.S. et al., 2021)

During severe exposure, cadmium can cause cancer in humans, notably cancers of the breast, oesophagus, intestines, lungs, stomach, testicles, and possibly the gallbladder. This is the main health issue associated with cadmium. Gallstones have been linked to the gallbladder in studies where they have been tested for the heavy metal contact in patients with gallbladder cancer. In many situations, gallstones have been linked as a precancerous scenario. When statistically substantial proportions of heavy metal concentration were analyzed, cadmium and other heavy metals were found to have higher concentrations. In terms of human health, the connection between cadmium and carcinogenicity is crucial. Patients with gliomas (brain cancer) had high levels of cadmium, indicating a potential link between heavy metal exposure and brain cancer. The pancreas is a body organ that has reportedly been connected to cancer after cadmium exposure. Moreover, the development of blood diseases, particularly chronic myeloid and lymphoblastic leukemia, has been linked to cadmium. Patients with leukemia were shown to have higher cadmium amounts when evaluated in comparison to controls, along with lower magnesium levels in both the blood and serum. The link between cadmium in urine and the occurrence of gastrointestinal cancer is another noteworthy connection between elevated cadmium levels and carcinogenicity. (Gallicchio V.S. et al., 2021)

Together with lead, other heavy metals have also been discovered that are known to harm human health, especially in children where they may obstruct myelin growth and hinder neurological development. The results of a study of kidney cancer patients that the cancer was related with high levels of lead were later corroborated by evidence linking the development of renal cell carcinoma with the existence of lead in the blood. Excessive levels of lead and a number of other heavy metals have indeed been linked to the onset of liver disease. Testing for gallstones found a potential link between elevated lead levels and gallbladder illness, which may result in a precancerous lesion. (Gallicchio V.S. et al., 2021)

According to a recent study conducted by Hussain S. et al. in 2019 the research findings revealed the presence of several types of cancer in the Kargil Ladakh region. Due to the excessive intake of heavy metals through food consumption, there is a possibility of a notable increase in the occurrence of cancer cases in this area in the future.

Table 2.3: Effects of Heavy metals on Human health

HEAVY METAL	DISEASES CAUSED BY EXPOSURE
As	Bronchitis, Cardiovascular and Neurological effects, Increased risk of various cancers (e.g., lung, bladder, kidney), Dermatitis
Cd	Kidney damage, Increased risk of lung cancer, Gastrointestinal disorder, Bone marrow cancer, Bronchitis
Cr	Rapid hair loss, Increased risk of lung cancer, Respiration problem
Cu	Failure of brain and kidney, Gastrointestinal symptoms (e.g., nausea, vomiting), Liver damage, Severe anaemia, Wilson’s disease (copper accumulation disorder), Intestinal irritation
Pb	Liver damage, Cardiovascular effects, gastrointestinal damage, Neurological and developmental disorders
Mn	Respiratory effects, Impaired cognitive function, Neurological disorders (e.g., Parkinson's-like symptoms)
Hg	Damage to nervous system (e.g., Minamata disease), Impaired development in infants and children, Cardiovascular effects
Ni	Immunotoxic, Dermatitis (skin irritation), neurotoxic, Respiratory effects (e.g., asthma), Genotoxic, Increased risk of lung cancer Hepatotoxic, throat and stomach cancers, rapid hair fall,
Zn	Gastrointestinal symptoms (e.g., nausea, vomiting), cause damage to nervous membrane, Respiratory effects (e.g., metal fume fever)

2.6. Pathway of the heavy metals in the food web

In a study conducted by Adimalla N. in 2020, the contamination of metals, including As, Cr, Cu, Zn, Ni, and Pb, were examined in the soil of 32 urban cities in India. The research also assessed the potential health risks associated with these heavy metals for both children and adults. As heavy metals can enter the human body through inhalation, epidermal contact, and ingestion, long-term exposure to soil heavy metals has been found to pose a significant risk to human health. Irrespective of whether the exposure levels are high or low, prolonged exposure to different concentrations of heavy metals in urban soil resulting from various human activities can have detrimental effects on human health. It is crucial to understand the extent of heavy metal contamination in urban soils, their adverse impacts on human health, and the geographical distribution patterns in order to prioritize the mitigation of heavy metal contamination and ensure the well-being of the population.

Health risk assessment is a methodical process constructed to estimate likely undesirable health effects associated with exposure to a variety of hazards, such as metals, pollutants, or environmental stressors. It involves the identification of hazards, estimation of exposure levels, and assessment of potential health impacts on individuals or populations. (Giri A. et al., 2021) It utilizes formulas to calculate non-carcinogenic and carcinogenic risk factors which include EDI, THQ, HI and CR.

Estimated daily intake (EDI)

$$EDI = \frac{C_M \times F_{IR} \times E_F \times E_D \times C_F}{B_W \times T_A} \times 10^{-3} \quad \ldots(1)$$

Where,

C_M – Metal Concentration

F_{IR} – Recommended daily allowance (RDA) of water consumption

E_D – Exposure Duration

C_F – Conversion Factor

E_F – Exposure Frequency

B_W – Average body weight for an adult

T_A – Average exposure time

RfD – Oral reference dose

CSFo – Carcinogenic slope factor

Target Hazard quotient (THQ)

$$THQ = \frac{EDI}{RfD} \quad \text{...(2)}$$

Hazard Index (HI)

$$HI = \Sigma^{i}_{(n=1)} THQ; i = 1,2,3,\ldots, n \quad \text{...(3)}$$

Carcinogenic Risk Factor (CR)

$$CR = EDI \times CSFo \quad \text{...(4)}$$

$$TCR = \Sigma^{i}_{(n=1)} CR; i = 1,2,3,\ldots,n \quad \text{...(5)}$$

Bhatia A. et al. in 2015 studied that vegetable crops can lead to heavy metal exposure through dietary intake. Specifically, Cd, Pb, Zn, and Cu were identified as posing a risk to human health. Metal pollution of wastewater-irrigated soils and ultimately the food chain is a risk that arises when heavy metals are not eliminated even after treatment. Through the ingestion of tainted fruits, vegetables, milk, and water, heavy metals can pose a health concern. Because peri-urban crops serve as bio-sinks and absorb metals in their tissues, they are susceptible to becoming saturated with heavy metals when cultivated on contaminated soil. Metal-containing aerosols are present in peri-urban vegetable producing areas, where they can either settle on leaves and adsorb or infiltrate the soil and affect the vegetables. (Bhatia A. et al., 2015)

Wastewater can contain different metals such as Zn, Cu, Pb, Mg, Ni, Cr, and Cd, depending on their respective sources of origin. Metal buildup in soil and vegetables cultivated there may result from continuous watering of agricultural land. At low concentrations, metals like Cu and Zn are necessary for many biological activities and biochemical action, but they can be hazardous at higher doses. Lead and cadmium are poisonous at low doses and do not appear to play any recognized important roles in the bodies of organisms. Consuming foods contaminated with heavy metals can substantially deplete the body of important nutrients, impairing psychosocial functioning, impairing intrauterine growth, producing developmental impairments linked to undernutrition, and increasing the risk of gastrointestinal cancer. (Bhatia A. et al., 2015)

Because vegetables grown in a belt are both utilized in the vicinity and shipped to additional areas, buildup of metals in their edible components may have a direct impact on consumers' health both nearby and far away. Hence, a significant portion, approximately 30-40% of the overall population, who regularly consume these vegetables, may have concerns regarding the presence of metal pollutants in these crops. (Bhatia A. et al., 2015)

The capability of vegetation to transmit metals to edible tissues from soil can be assessed using the transfer factor of metals. Metals with a high transfer factor can move from the soil more readily to plants' edible portions than those with a low transfer factor. Cd had the largest transfer factor, most likely as a result of the rapid agility into edible tissue from soil. In comparison to Pb, Cd and Zn are to a greater extent transportable elements. The average sequence of metal uptake by plants from soils was Cd>Zn>Cu>Pb. Levels of cadmium, lead, and zinc that exceed permitted limits. (Bhatia A. et al., 2015)

Dairy products in particular, which include high levels of protein, vitamins, and minerals, are particularly vital for newborn nutrition and play a significant role in the human diet. Due to claimed health advantages over heat-treated milk, such as higher nutritional value and the potential for probiotic microorganisms, raw milk intake has recently been on the rise. (Miclean M. et al., 2019)

Due to claimed health advantages over heat-treated milk, such as higher nutritional value and the potential for probiotic microorganisms, raw milk intake has recently been on the rise. (Miclean M. et al., 2019)

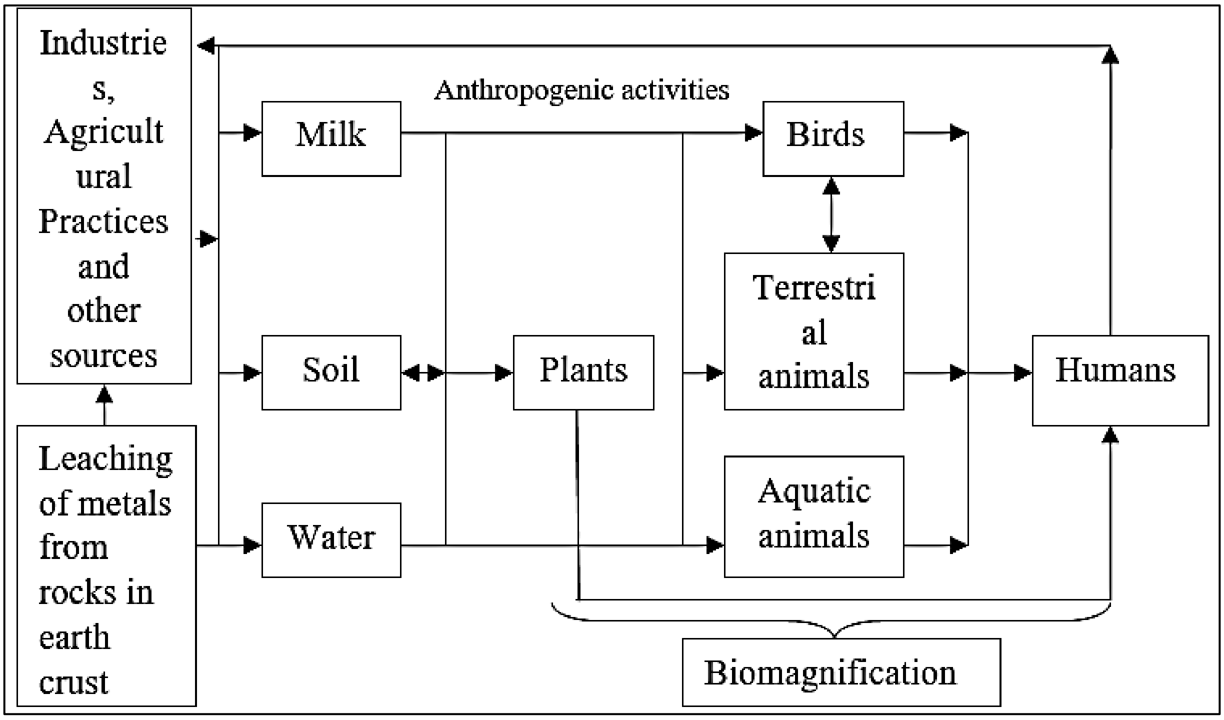

Fig 2.4: Pathway of heavy metals into the food web

As humans occupy the highest position in the food chain, they are subjected to substantial levels of pollutants. (Miclean M. et al., 2019)

The majority of metals can be transmitted to plants that are then utilized as animal feed. After passing through an animal's digestive system, these metals accumulate in lipid-rich tissues and are largely expelled through milk. Additionally, while grazing, animals can consume substantial volumes of soil. Metals can enter the human body through three different routes: soil to fodder, fodder to milk and milk to human. (Miclean M. et al., 2019)

Giri A. et al. conducted a study which observed presence of metals in dairy milk. The study also evaluated the potential health risks associated with milk consumption. Throughout the year, the levels of most metals, except for Zn, did not show significant variations. The cancer risk (CR) and non-carcinogenic parameters were found to be within permissible limits. The study indicated that the cumulative CR was nearing the threshold level, suggesting that long-term consumption of dairy milk may have an impact in the future due to the cumulative effects of each metal. This could be attributed to the occurrence of elevated levels of metals in the major fodder plants.

Miclean M. et al. in 2019 reported that all water, soil, pasture, and milk samples tested contained Cu, Pb, Cd, and Zn, suggesting possible contamination. The average concentration of metals in soil decreased in the order of Zn > Pb > Cu > Cd, while in water, fodder, and milk, the order was Zn > Cu > Pb > Cd. A majority of the soil samples analyzed exceeded the threshold levels for Pb and Cd, while approximately one-third exceeded the thresholds for Cu and Zn. Only one sample surpassed the intervention level for Cu. Pb, a hazardous metal known to cause cancer, exceeded the allowable limit in half of the milk samples, despite low metal concentrations in water and moderate levels in fodder. This indicates that the milk was unsuitable for human consumption. Other potential sources of metal intake besides food and water were identified, including grazing on contaminated soil adhered to plants and the incorporation of contaminated soil into feed during the feed manufacturing process. The risk assessment results indicated no non-carcinogenic health risks for the local population in the study area. However, there may be carcinogenic risks associated with prolonged exposure to Cd through milk consumption. (Miclean M. et al., 2019)

Giri A. et al. in 2022, observed that spinach exhibited high levels of most metals compared to wheat and cabbage. The cumulative CR was near to the threshold level; therefore, the combined actions of each element might have little effect. There is a strong likelihood that the CR level will continue to grow and may exceed the limit in the near future due to the area's fast development, changing climatic patterns, increased tourist traffic, and resultant pollution. Consequently, in the future, increasing vegetable consumption may have both more positive and negative consequences on the people of Ladakh, India.

In a study conducted by Yasotha A. et al. in 2020 it was reported that the milk samples had the highest concentrations of Cd and Pb, measuring 0.18 mg L-1 and 0.37 mg L-1, respectively, which exceeded the internationally accepted range. Zn, Cd, and Pb were the most frequently detected metals in milk, with 63.7%, 51.2%, and 41.2% of children being exposed to levels exceeding the recommended dosage for each of these metals, respectively. There was a significant positive correlation observed between the concentrations of studied heavy metals in water and milk, except for Zn. Cu and Cd concentrations in milk and pasture samples were also found to have statistically significant positive associations. These findings highlight the potential health risks posed by the population's exposure to Pb, Cd, and Zn.

3. METHODOLOGY AND MATERIALS USED

3.1. Assessment of study site

Current investigation took place in the Leh district of Union Territory Ladakh, India. Study site in Leh district spans from approximately 32° to 36° latitude and 75° to 80° longitude, with elevations from 2946 to 5994 meters above sea level. This region is characterized by its high altitude, cold desert environment, and is geographically situated amidst the Indus and Zanskar Rivers, shielded by the Himalayas from rainfall. The temperature in this area spans from -40°C to +40°C, while the average relative humidity ranges between 24.70% and 39.03%.

Fig 3.1: Map of survey sites of Leh

3.2.Chemicals and reagents used

To analyse various water and soil quality limits and heavy metals, chemicals and reagents were purchased from Loba Chemie and standards used in estimating heavy metals (Cu, Co, Fe, Zn, Cr and Ni) were purchased from Sisco Research Laboratories whereas hollow cathode lamps, both single and multi-element, used in estimating heavy metals (Cu, Cr, Co, Fe, Zn, and Ni) were purchased from Perkin Elmer.

Table 3.1: Chemicals and reagents used in water sample analysis

BLANKS USED		
CONCENTRATION	VOLUME OF ACID	VOLUME OF DISTILLED WATER
1% HCl	10 ml HCl	990 ml distilled water
1% HNO_3	10 ml HNO_3	990 ml distilled water
STANDARDS USED		
METAL	CONCENTRATIONS	BLANK USED
Cu	2 mg/ 100 ml	1% HNO_3
	5 mg/ 100 ml	
	15 mg/ 100 ml	
Fe	0.1 mg/ 100 ml	1% HNO_3
	1 mg/ 100 ml	
	10 mg/ 100 ml	
Ni	2 mg/ 100 ml	1% HNO_3
	5 mg/ 100 ml	
	15 mg/ 100 ml	
Co	3.5 mg/ L	1% HCl
Zn	1 mg/ 100 ml	1% HCl
Cr	5 mg/ L	1% HNO_3

3.3. Collection of water samples

Samples of water were gathered from the Leh region of Ladakh, which serves as the primary residential area for the majority of the population. The collection sites included groundwater sources, tap water outlets, natural springs, and river water from different locations; a total of sixteen water samples were collected.

Table 3.2: Water samples collected from multiple study sites of Leh

S. No.	WATER SAMPLE	STUDY SITE	ALTITUDE	DISTANCE FROM LEH CITY
1.	Leh tap water	Leh	3500 m	0 km
2.	Shey river water	Shey	3250 m	6 km
3.	Ney ground water	Ney	3634 m	52.1 km
4.	Basgo spring water	Basgo	3292 m	39.4 km
5.	Campus water ground/tap	Leh	3500 m	2.1 km
6.	Nimu ground water	Nimu	3140 m	34.1 km
7.	Skara ground water	Leh	3500 m	700 m
8.	Campus water ground/tap	Leh	3500 m	2.1 km
9.	Choglam tap water	Choglamsar	3353 m	5.1 km
10.	Choglam ground water	Choglamsar	3353 m	5.1 km
11.	Nimu river water	Nimu	3140 m	34.1 km
12.	Shey ground water	Shey	3415 m	13.1 km
13.	Skara tap water	Leh	3500 m	700 m
14.	Choglausal river water	Choglamsar	3353 m	5.1 km
15.	Basgo river water	Basgo	3292 m	39.4 km
16.	Leh ground water	Leh	3500 m	0 km

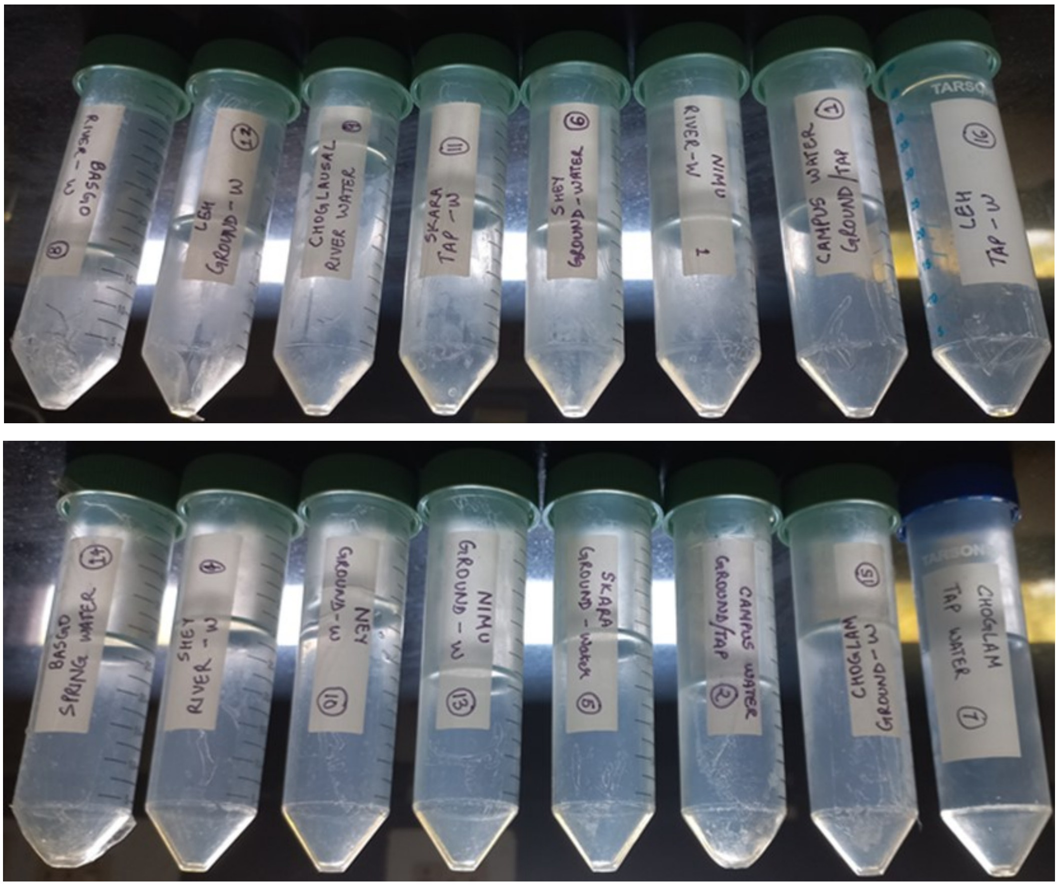

Fig 3.2: Water samples collected from multiple study sites of Leh

3.4. Collection of soil samples

Samples of soil were gathered from the Leh area of Ladakh where most of the population resides. Ten soil samples were collected from Leh.

Table 3.3: Soil samples collected from multiple study sites of Leh

SOIL SAMPLE	SAMPLE PICTURE	STUDY SITE	ALTITUDE	DISTANCE FROM LEH CITY
High Altitude Soil 1		Leh	3500 m	2.1 km
High Altitude Soil 2		Leh	3500 m	2.1 km
High Altitude Soil 3		Leh	3500 m	2.1 km
High Altitude Soil 4		Stok	3497 m	13.4 km
High Altitude Soil 5		Basgo	3292 m	39.4 km
High Altitude Soil 6		Taroo	3524 m	23 km

High Altitude Soil 7		Nimu	3140 m	34.1 km
High Altitude Soil 8		Saboo	3544 m	7.6 km
High Altitude Soil 9		Tunling village		
High Altitude Soil 10		Chuchot	3267 m	54.7 km

3.5. Physico-chemical analysis for water and soil samples

This analysis was carried out in DRDO-DIHAR Base Lab, Chandigarh. The instrument used for the measurement of pH, TDS, Salinity, Resistivity and Conductivity of the water samples was OAKTON PC2700 meter (Cole-Parmer, USA) and the instrument used to measure turbidity of the water samples was HACH 2100Q Portable turbidimeter (Hach Company, USA) along with the 20 NTU standard of formazin used for calibration. Instrument used for the measurement of pH of soil samples is EUTECH INSTRUMENTS pH 700 pH/ mV/ ^{0}C/ ^{0}F meter, Thermo Scientific, USA. To perform the measurement, the soil samples were combined with distilled water in a proportion of 1 part soil to 2 parts distilled water according to Tandon (1993).

To determine the levels of heavy metals, the water samples underwent filtration using a Whatman filter paper to eliminate solid impurities. Subsequently, the filtered water samples were subjected to centrifugation at 7000 rpm for a duration of 10 minutes to ensure the removal of any remaining solid particles.

Table 3.4: Physico-chemical and metal parameters along with their analytical techniques undertaken for water and soil samples

PARAMETER	ABBREVIATION	UNIT
pH	pH	-
Conductance	g	µS
Total Dissolved Solids	TDS	ppm
Salinity		ppm
Resistivity	ρ	KΩ
Turbidity	Turb	NTU
Textural class of soil	-	-
Metals	Cu, Co, Fe, Zn, Cr, Ni	mg/L

3.6. Treatment of soil for heavy metal analysis

The aqua regia digestion method is employed to measure the total concentration of trace elements in soils. This method involves treating a soil sample with a mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) in a 3:1 ratio. Aqua regia solution is widely accepted for its ability to fully extract various essential elements such as Cd, Cu, Pb, and Zn, including their sulphates, sulphides, oxides, and carbonates. However, it should be noted that this method only partially extracts most rock-forming elements such as Cr, Ni, and Ba. Despite this limitation, the aqua regia digestion method is globally recognized for soil analysis, acknowledging that the elements not extracted by this method may not be readily available for biological uptake.

3.7. Heavy metal analysis for water and soil samples

Thereafter, Cu, Co, Fe, Zn, Cr and Ni were estimated using Atomic Absorption Spectrometer (AAnalyst 4000, Perkin Elmer precisely, USA) by generating methods according to specific standard concentrations for each metal.

AAS optimized instrumental conditions are-

Fuel: Acetylene

Oxidant: Air

Fuel flow: 2.5 L/min

Oxidant flow: 10 L/min

Current: 30 mA

Regular instrument validation was conducted to determine the detection limit of metals. This involved analysing blank samples and calibration standards containing various metals. Test samples were analysed only after achieving satisfactory readings of metal concentrations in the blanks and standards.

4. RESULTS

4.1. Physicochemical properties of water of high-altitude cold desert region

The physicochemical properties in various water systems of Leh were presented in Table 4.1. The experimental outcomes of this study uncovered that pH varied from 7.38-8.14 whereas the total mean value was 7.799. The pH of the water samples collected from spring water, river water, ground water and tap water varied from 7.38-7.51, 7.42- 8.11, 7.43- 8.14 and 7.44- 7.98 whereas the mean value was 7.453, 7.825, 7.865 and 7.76.

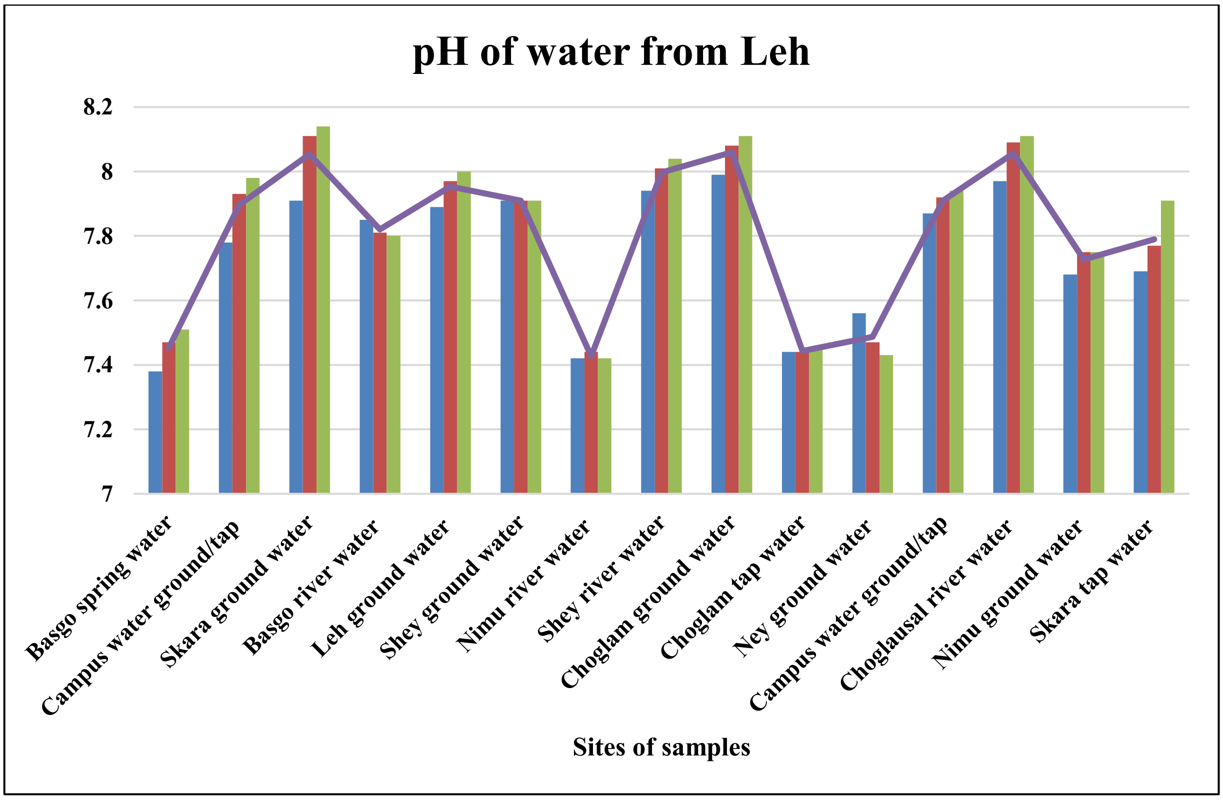

Fig 4.1: pH of water samples obtained from study sites in Leh

The conductance of water samples in this experimental study varied from 157.2- 986 µS whereas the total mean value is 378.287 µS. The conductance of the samples of water collected from spring water, ground water, river water and tap water varied from 169.2-170.4 µS, 188.6-425.4 µS, 157.2-458.8 µS and 417- 986 µS whereas the mean value was 169.83 µS, 315.799 µS, 321.3095 µS and 578.349 µS.

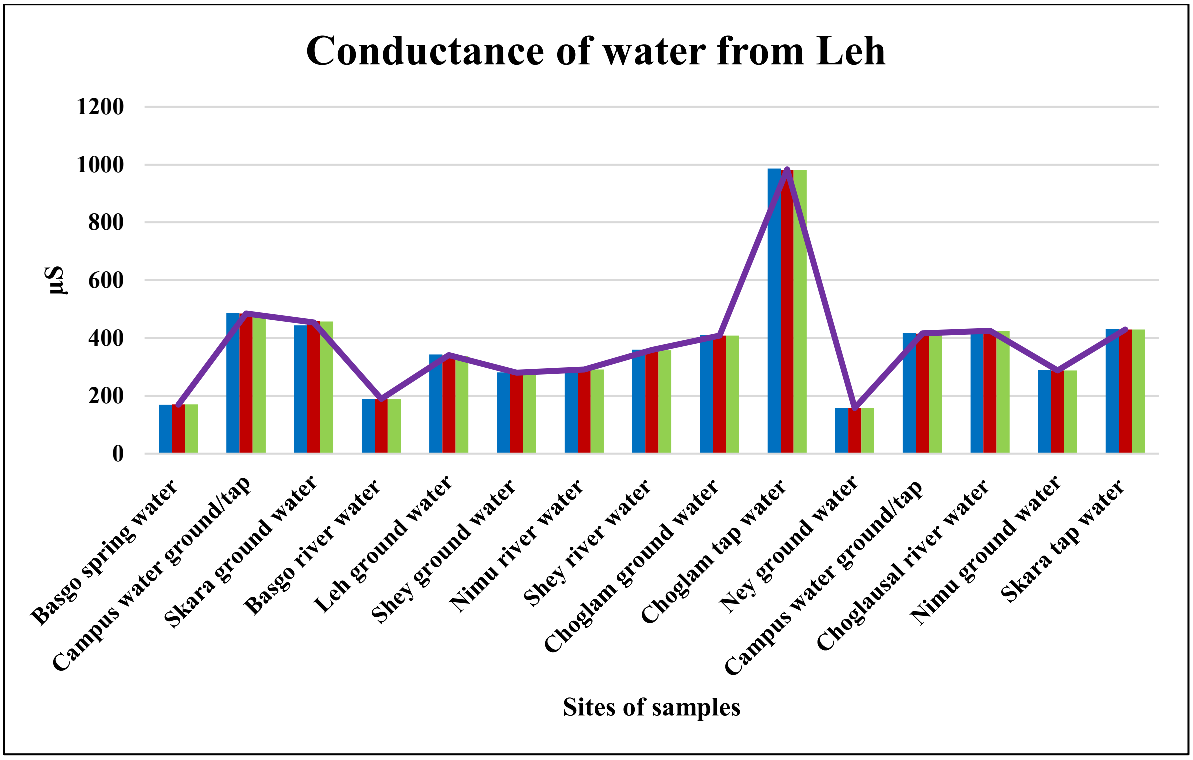

Fig 4.2: Conductance of water samples obtained from study sites in Leh

The total dissolved solids (TDS) of water samples in this experimental study varied from 131.6- 824.6 ppm whereas the total mean value is 316.449 ppm. The TDS of the water samples collected from spring water, river water, ground water and tap water varied from 141.2-142 ppm, 157.8- 355.8 ppm, 131.6- 383.9 ppm and 347.1- 824.6 ppm whereas the mean value is 141.7 ppm, 264.209 ppm, 268.737 ppm and 483. 943 ppm.

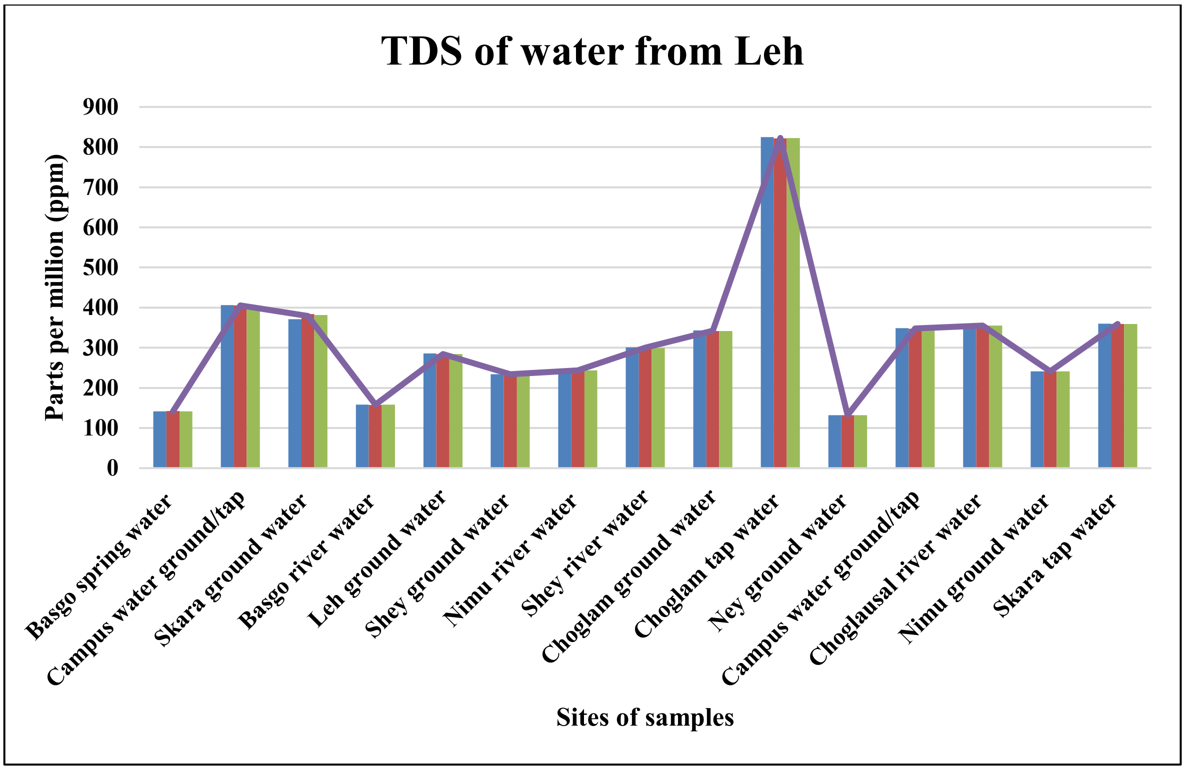

Fig 4.3: Total dissolved solids (TDS) of water samples obtained from study sites in Leh

The Salinity of water samples in this experimental study varied from 127.7- 830.9 ppm whereas the total mean value was 309.969 ppm. The salinity of the water samples collected from spring water, river water, ground water and tap water varied from 137- 137.5 ppm, 152.6- 347.2 ppm, 127.7- 375.4 ppm and 338.7- 830.9 ppm whereas the mean value was 137.3 ppm, 256.733 ppm, 261.343 ppm and 479.308 ppm.

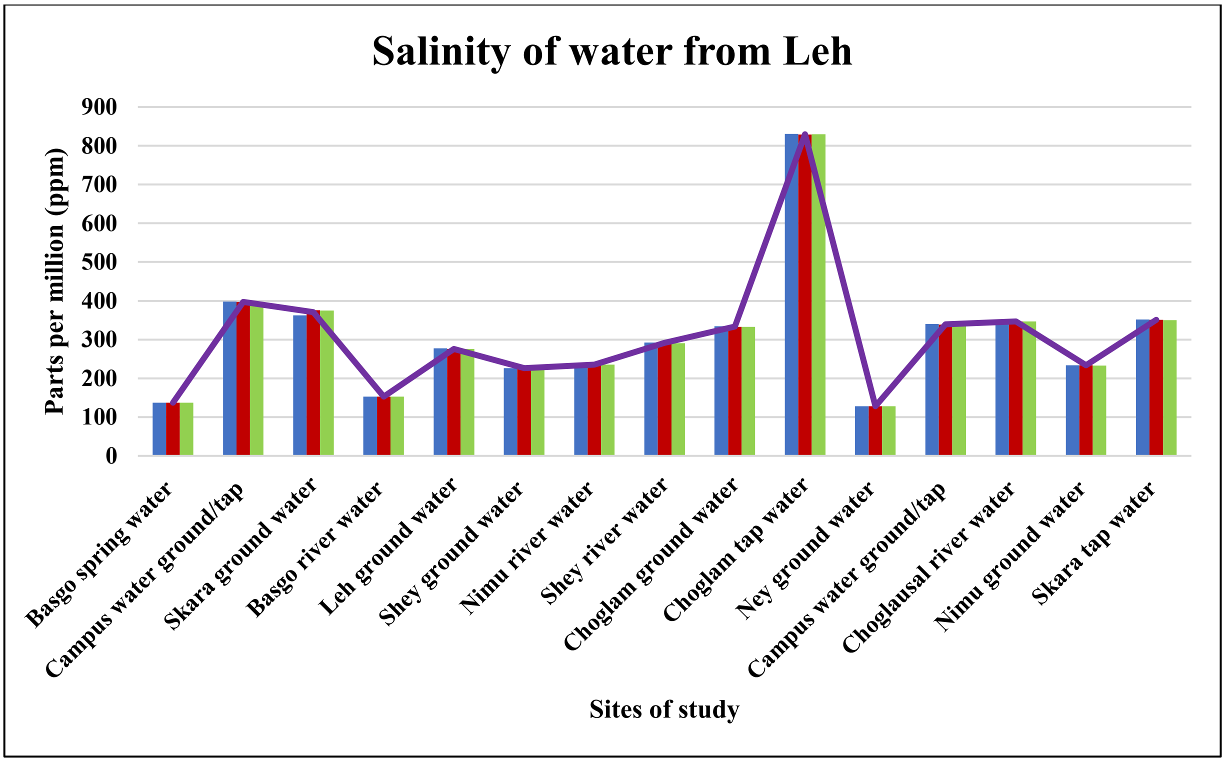

Fig 4.4: Salinity of water samples obtained from study sites in Leh

The resistivity of water samples in this experimental study varied from 0.6072-3.795 KΩ whereas the total mean value was 1.936 KΩ. The resistivity of the water samples collected from spring water, river water, ground water and tap water varied from 3.53-3.535 KΩ, 1.407- 3.168 KΩ, 1.304- 3.795 KΩ and 0.6072- 1.44 KΩ whereas the mean value was 3.533 KΩ, 2.0739 KΩ, 2.0903 KΩ and 1.169 KΩ.

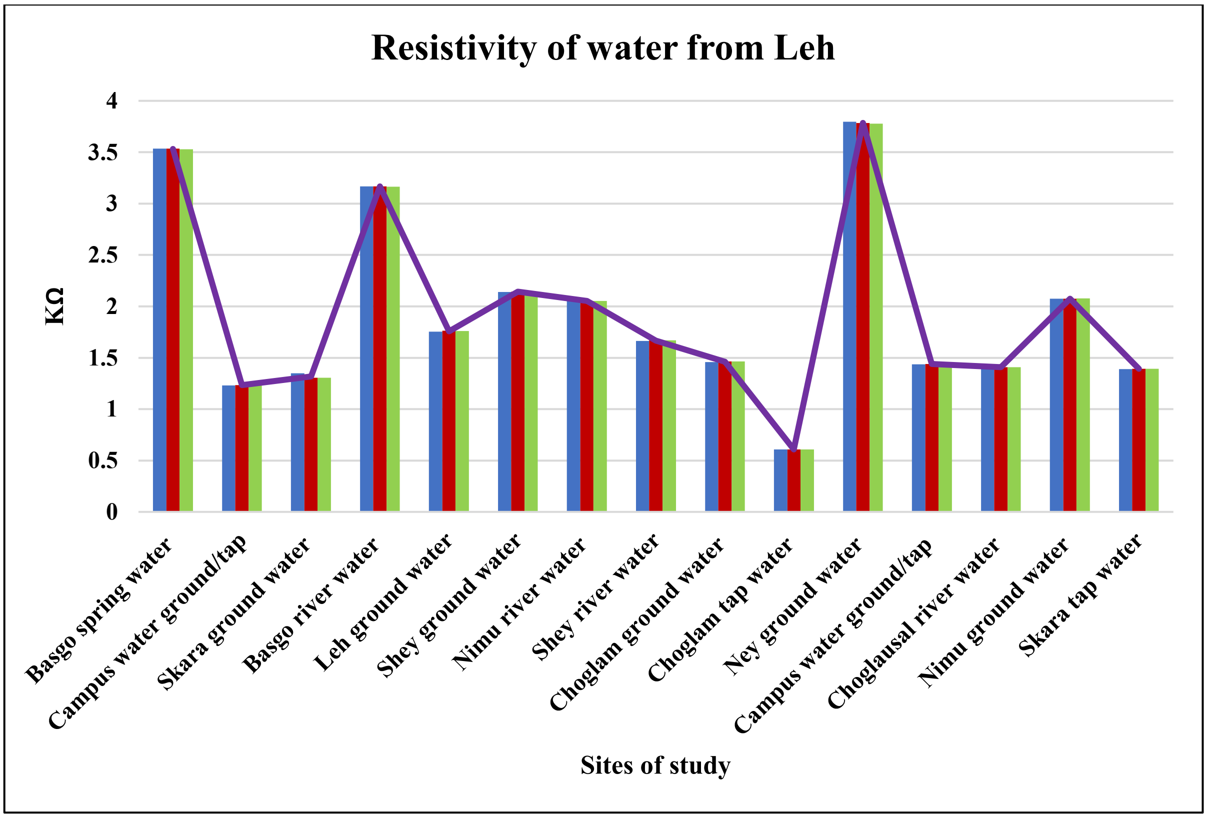

Fig 4.5: Resistivity of water samples obtained from study sites in Leh

The Turbidity of water samples in this experimental study varied from 1-11.6 NTU whereas the total mean value was 2.446 NTU. The turbidity of the water samples collected from spring water, river water, ground water and tap water varied from 1.9-2.26 NTU, 1.18-4.33 NTU, 1- 3.47 NTU and 1.1-11.6 NTU whereas the mean value was 2.07 NTU, 2.3066 NTU, 1.782 NTU and 3.676 NTU.

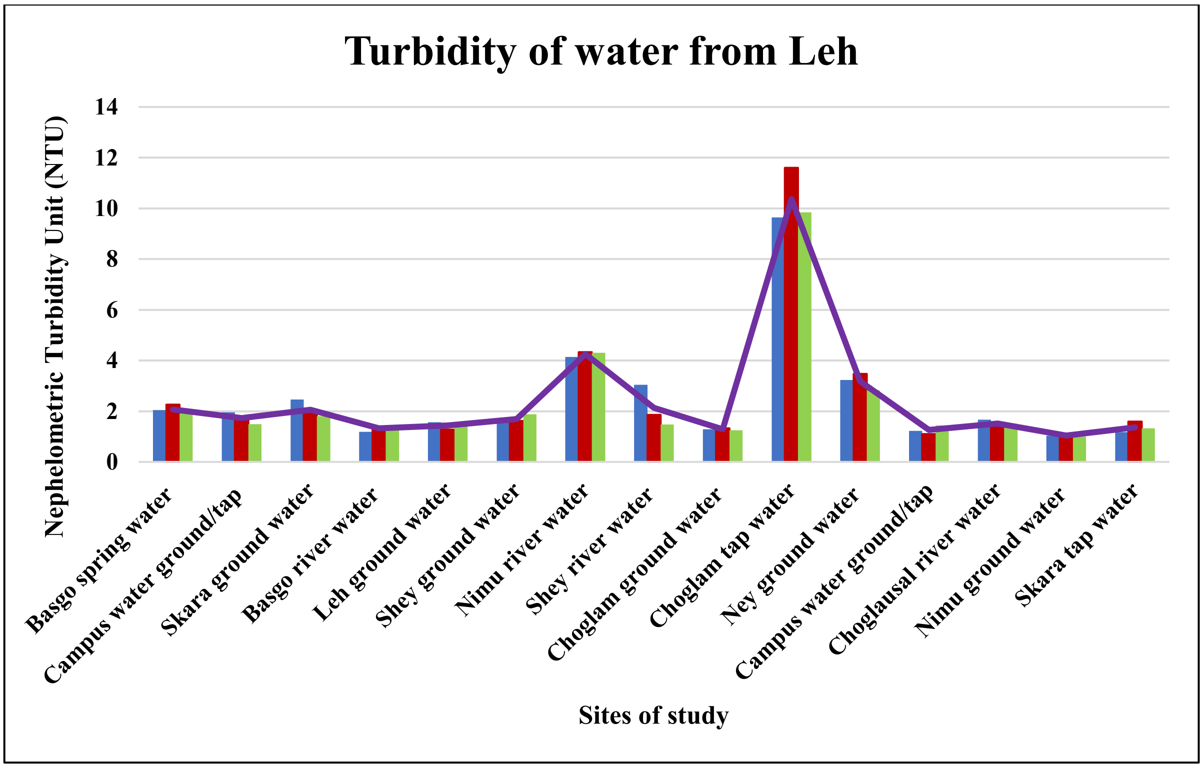

Fig 4.6: Turbidity of water samples obtained from study sites in Leh

Table 4.1: Physico-chemical characteristics of water samples from various study sites of Leh

Water Samples	pH	Conductance (µS)	TDS (ppm)	Salinity (ppm)	Resistivity (KΩ)	Turbidity (NTU)
Standards	**6.5-8.5**	**200-800 µS/cm**	**250-300 ppm**	**600-900 ppm**	**2-200 Ωm**	**<5NTU**
Basgo spring water	7.453	169.83	141.7	137.3	3.53	2.07
Campus water ground/tap	7.8967	484.767	405.67	397.5	1.23	1.7267
Skara ground water	8.053	453.23	378.9	370.7	1.3193	2.0567

Basgo river water	7.82	188.867	157.967	152.67	3.1663	1.323
Leh ground water	7.953	340.5	284.63	276.23	1.7583	1.443
Shey ground water	7.91	279.567	233.73	226.1	2.14167	1.69
Nimu river water	7.4267	290.93	243.467	235.8	2.054	4.2567
Shey river water	7.9967	358.63	300	291.53	1.668	2.1267
Choglam ground water	8.06	408.9	342.13	333.6	1.4623	1.2867
Choglam tap water	7.443	983.4	822.867	829.6	0.607767	10.363
Ney ground water	7.4867	157.63	132	128.03	3.7853	3.1767
Campus water ground/tap	7.91	415.63	347.767	339.2	1.43867	1.2567
Choglausal river water	8.0567	424.767	355.4	346.93	1.4073	1.52
Nimu ground water	7.7267	288.03	241.03	233.4	2.075	1.04
Skara tap water	7.79	429.6	359.467	350.93	1.392	1.36

4.2. Physico-chemical properties of soil of high-altitude cold desert region

The physicochemical properties in various soil systems of Leh are presented in Table 4.2. The experimental results of this study revealed that the pH varies from 8.17- 9.15

whereas the total mean value is 8.829 whereas the textural classification of the soil samples from al the study sites is sandy in nature.

Table 4.2: Physico-chemical characteristics of soil samples from various study sites of Leh

Soil Sample	Study Site	Altitude	pH	Textural Class
High Altitude Soil 1	Leh	3500 m	8.17	Sandy
High Altitude Soil 2	Leh	3500 m	8.89	Sandy
High Altitude Soil 3	Leh	3500 m	9.03	Sandy
High Altitude Soil 4	Stok	3497 m	8.75	Sandy
High Altitude Soil 5	Basgo	3292 m	9.09	Sandy
High Altitude Soil 6	Taroo	3524 m	9.15	Sandy
High Altitude Soil 7	Nimu	3140 m	8.91	Sandy
High Altitude Soil 8	Saboo	3544 m	8.78	Sandy
High Altitude Soil 9	Tunling village		8.44	Sandy
High Altitude Soil 10	Chuchot	3267 m	9.08	Sandy

4.3. Levels of heavy metals in water of high-altitude cold desert region

The levels of heavy metal present in various water systems of Leh were presented in Table 4.2. The experimental results of this study revealed that the copper concentration varied from 0.016-0.269 mg/L whereas the total mean value was 0.061 ±0.03 mg/L. The highest intensity of copper present among the samples of water gathered from various study sites was 0.269 ±0.01 mg/L in Choglam tap water and the least concentration of copper present among water samples gathered from these study sites was 0.016 ±0.026 mg/L in Campus ground/tap water.

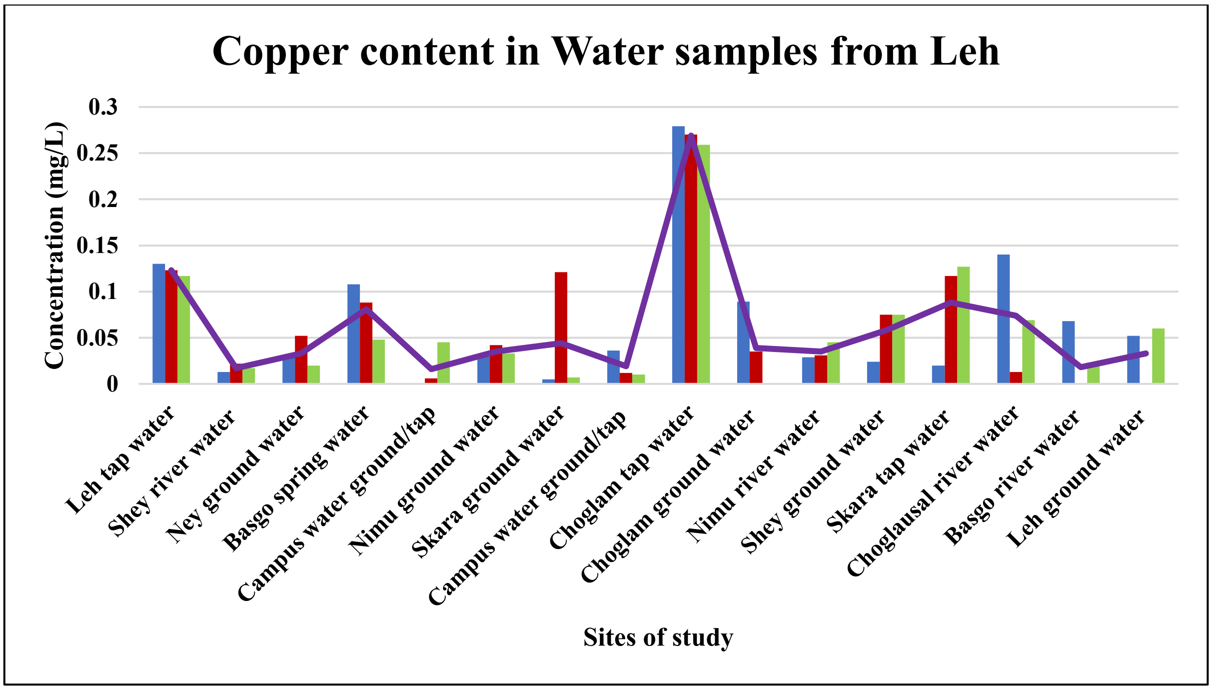

Fig 4.7: Concentration of copper present in water samples obtained from various study sites in Leh

The concentration of nickel detected in this study varies from 0.013-0.076 mg/L whereas the total mean value is 0.036 ±0.013 mg/L. The highest intensity of copper present among the samples of water gathered from various study sites was 0.076 ±0.015 mg/L in Choglam tap water and the least concentration of nickel present among water samples gathered from these study sites was 0.013 ±0.005 mg/L in Basgo river water.

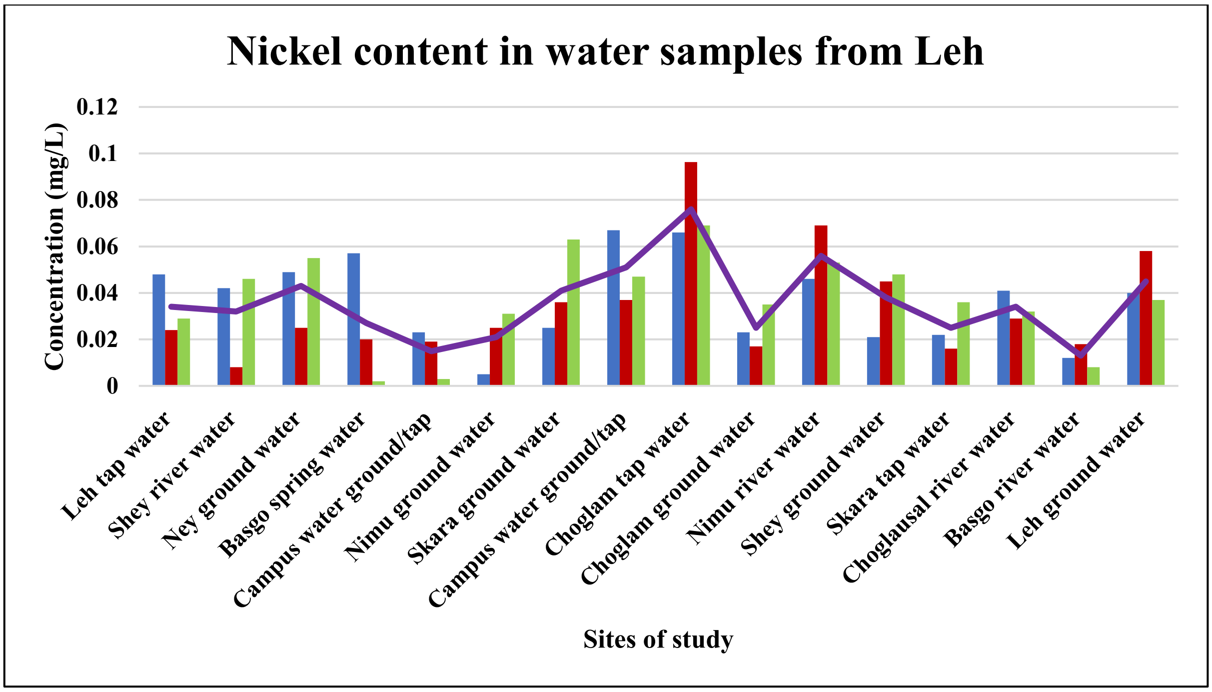

Fig 4.8: Concentration of nickel present in water samples obtained from various study sites in Leh

The concentration of cobalt detected in this study varies from 0.006-0.058 mg/L whereas the total mean value is 0.031 ±0.017 mg/L. The highest intensity of copper present among the samples of water gathered from various study sites was 0.058 ±0.015 mg/L in Nimu river water and the least concentration of cobalt present water samples gathered from these study sites was 0.006 ±0.006 mg/L in Shey ground water.

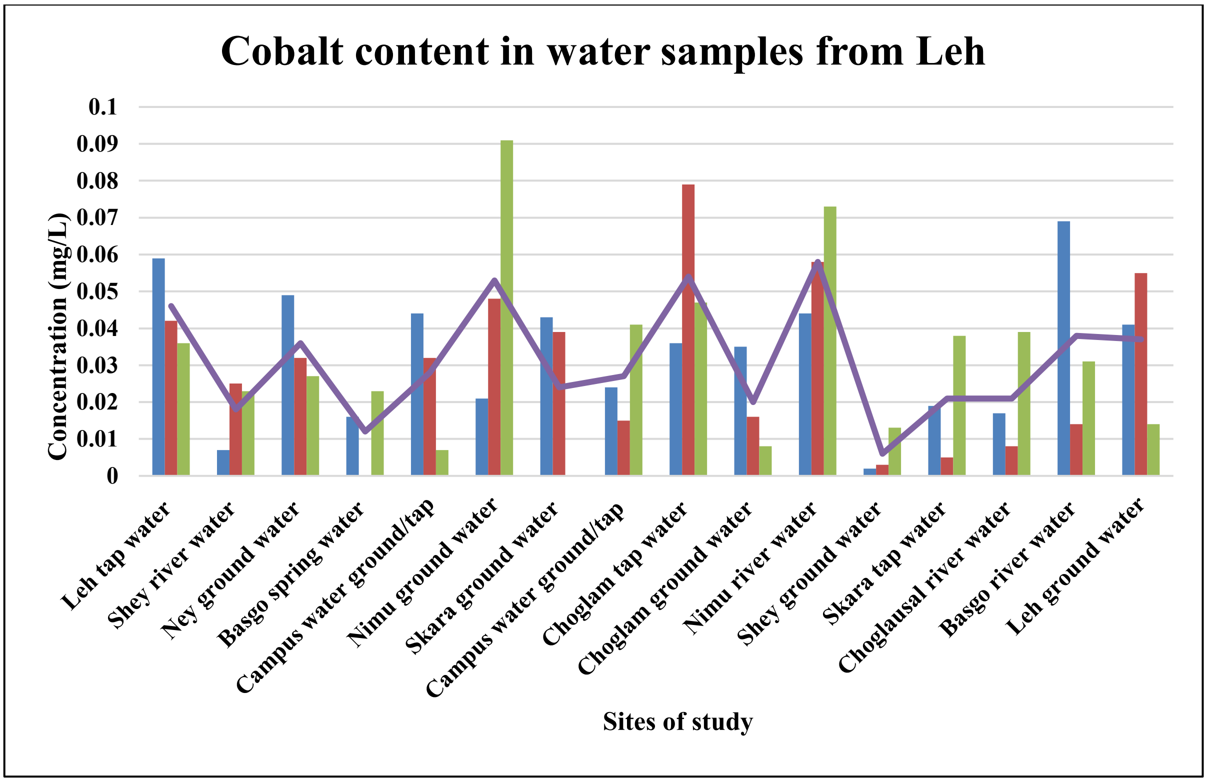

Fig 4.9: Concentration of cobalt present in water samples obtained from various study sites in Leh

The concentration of zinc detected in this study varies from being absent to 0.397 mg/L whereas the total mean value is 0.056 ±0.011 mg/L. The highest intensity of copper present among the samples of water gathered from various study sites was 0.397 ±0.005 mg/L in Ney ground water and zinc was found to be absent in Shey river water, Basgo spring water, Campus ground/tap water, Nimu river water, Choglam ground water, Skara tap water, Choglausal river water, Leh ground water.

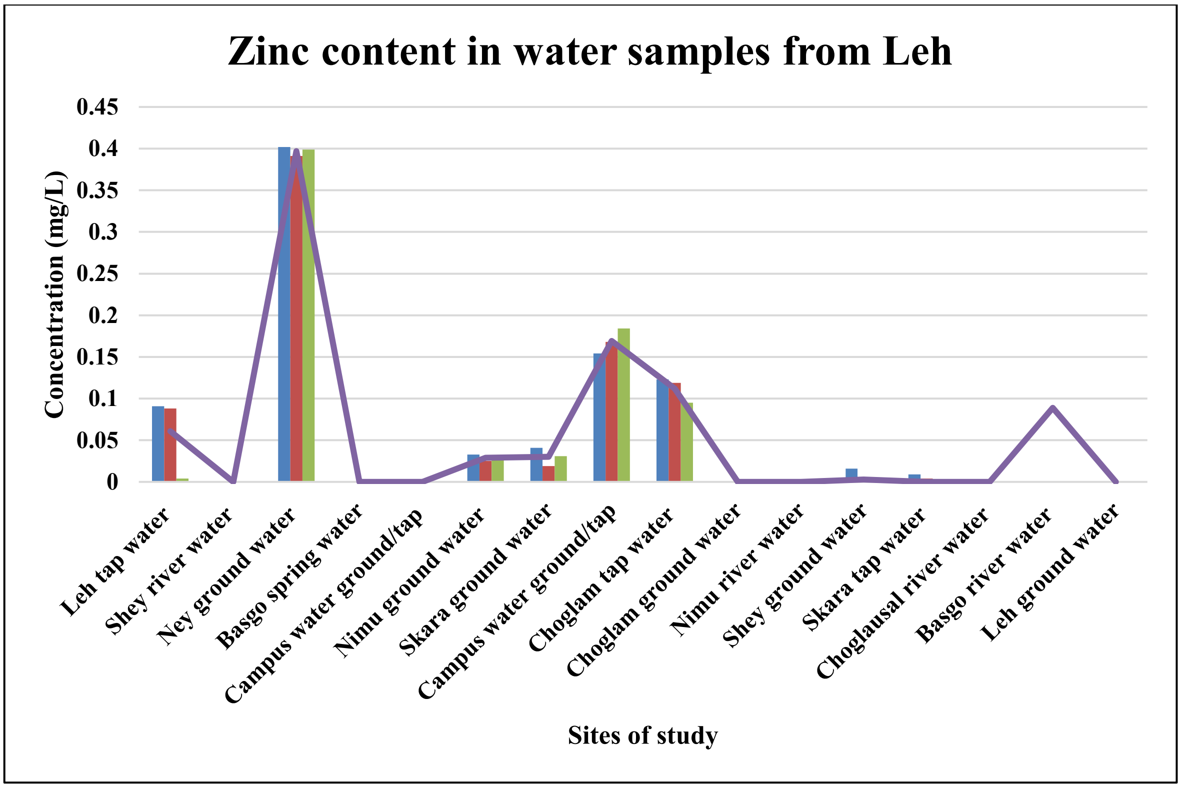

Fig 4.10: Concentration of Zinc present in water samples obtained from various study sites in Leh

The concentration of iron detected in this study varies from being absent to 0.065 mg/L whereas total mean value is 0.033 ±0.023 mg/L. The highest intensity of copper present among the samples of water gathered from various study sites was 0.065 ±0.021 mg/L in Leh ground water and the iron was found to be absent in Skara ground water.

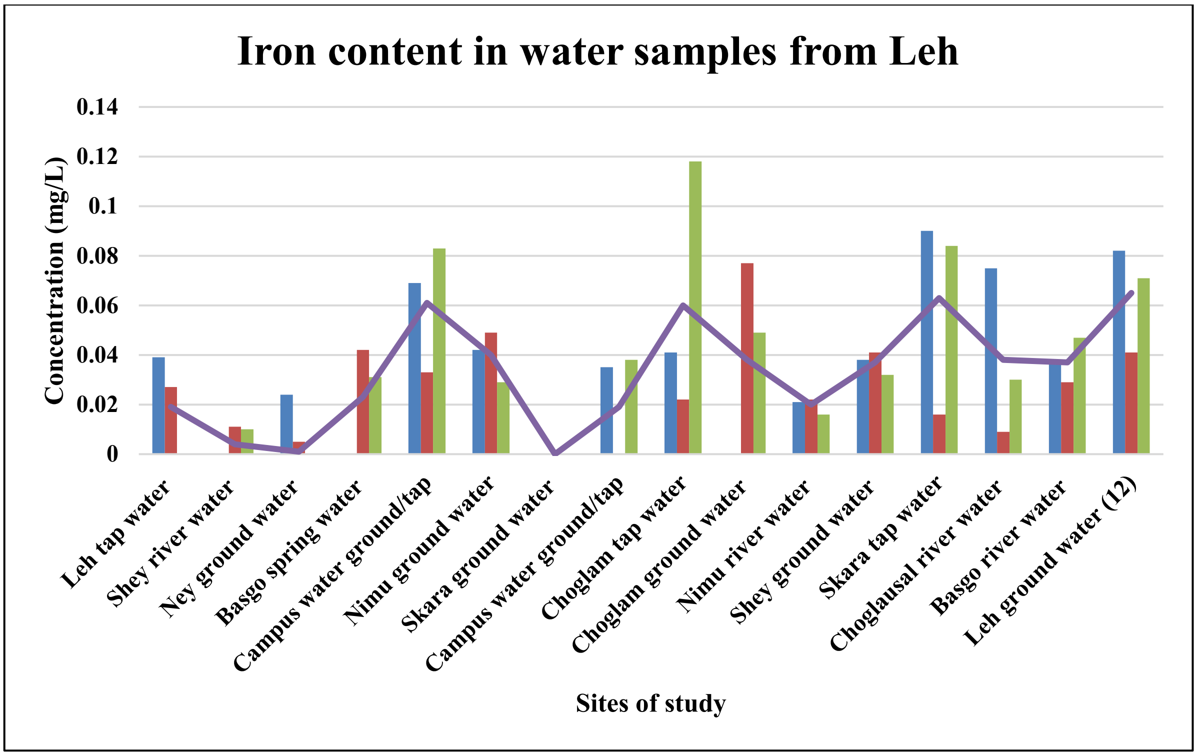

Fig 4.11: Concentration of Iron present in water samples obtained from various study sites in Leh

Table 4.3: Heavy metal concentration in water from various study sites of Leh

Water Sample	**Cu (mg/L)**	**Ni (mg/L)**	**Co (mg/L)**	**Zn (mg/L)**	**Fe (mg/L)**
WHO Standard (mg/L)	**2.00**	**0.02**	**0.05**	**3.00**	**0.3**
Leh tap water	0.123 ±0.006	0.034 ±0.012	0.046 ±0.012	0.061 ±0.049	0.019 ±0.023
Shey river water	0.017 ±0.005	0.032 ±0.021	0.018 ±0.01	0.095 ±0.007	0.004 ±0.011
Ney ground water	0.033 ±0.017	0.043 ±0.016	0.036 ±0.012	0.397 ±0.005	0.001 ±0.025
Basgo spring water	0.081 ±0.03	0.027 ±0.028	0.012 ±0.014	Absent	0.023 ±0.024
Campus water ground/tap	0.016 ±0.026	0.015 ±0.01	0.028 ±0.019	Absent	0.061 ±0.026

Nimu ground water	0.035 ±0.006	0.021 ±0.014	0.053 ±0.035	0.029 ±0.004	0.04 ±0.010
Skara ground water	0.044 ±0.067	0.041 ±0.02	0.024 ±0.029	0.03 ±0.011	Absent
Campus water ground/tap	0.019 ±0.014	0.051 ±0.015	0.027 ±0.013	0.169 ±0.015	0.019 ±0.031
Choglam tap water	0.269 ±0.01	0.076 ±0.015	0.021 ±0.031	0.112 ±0.015	0.06 ±0.051
Choglam ground water	0.039 ±0.048	0.025 ±0.009	0.02 ±0.014	Absent	0.038 ±0.045
Nimu river water	0.035 ±0.009	0.056 ±0.011	0.058 ±0.015	Absent	0.02 ±0.003
Shey ground water	0.058 ±0.029	0.038 ±0.015	0.006 ±0.006	0.011	0.037 ±0.005
Skara tap water	0.088 ±0.059	0.025 ±0.01	0.021 ±0.016	0 ±0.012	0.063 ±0.042
Choglausal river water	0.074 ±0.064	0.034 ±0.006	0.021 ±0.016	Absent	0.038 ±0.034
Basgo river water	0.018 ±0.053	0.013 ±0.005	0.038 ±0.028	0.089 ±0.014	0.037 ±0.009
Leh ground water	0.033 ±0.041	0.045 ±0.011	0.037 ±0.021	Absent	0.065 ±0.021

4.4. Levels of heavy metals in soil of high-altitude cold desert region

The concentration of copper detected in this study varies from 18.5- 192.1 mg/kg whereas the total mean value is 58.9 ±6.23 mg/kg. The highest concentration of copper present among the soil samples collected from various study sites was found to be 192.1 ±3.2 mg/kg in Saboo and the least concentration of copper present among the soil samples collected from these study sites was found to be 18.5 ±1.2 mg/kg in Taroo.

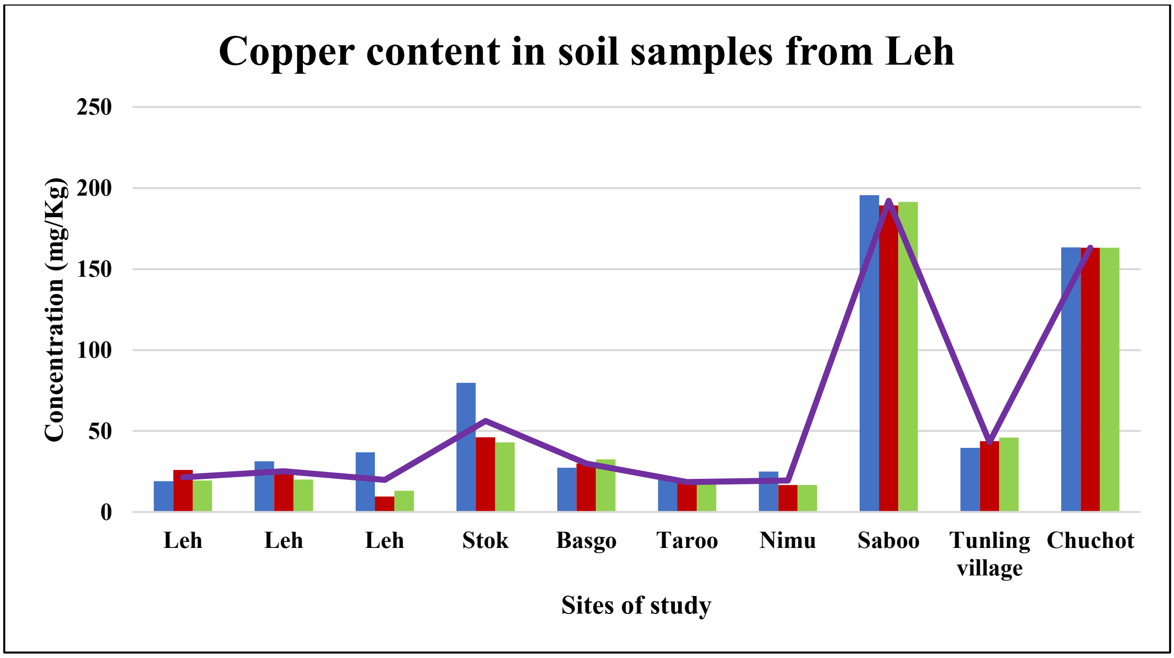

Fig 4.12: Concentration of copper present in soil samples obtained from various study sites in Leh

The concentration of nickel detected in this study varies from 22.1- 70.4 mg/kg whereas the total mean value is 36.88 ±3.63 mg/kg. The highest concentration of nickel present among the soil samples collected from various study sites was found to be 70.4 ±3.8 mg/kg in Chuchot and the least concentration of nickel present among the soil samples collected from these study sites was found to be 22.1 ±3.2 mg/kg in Tunling village.

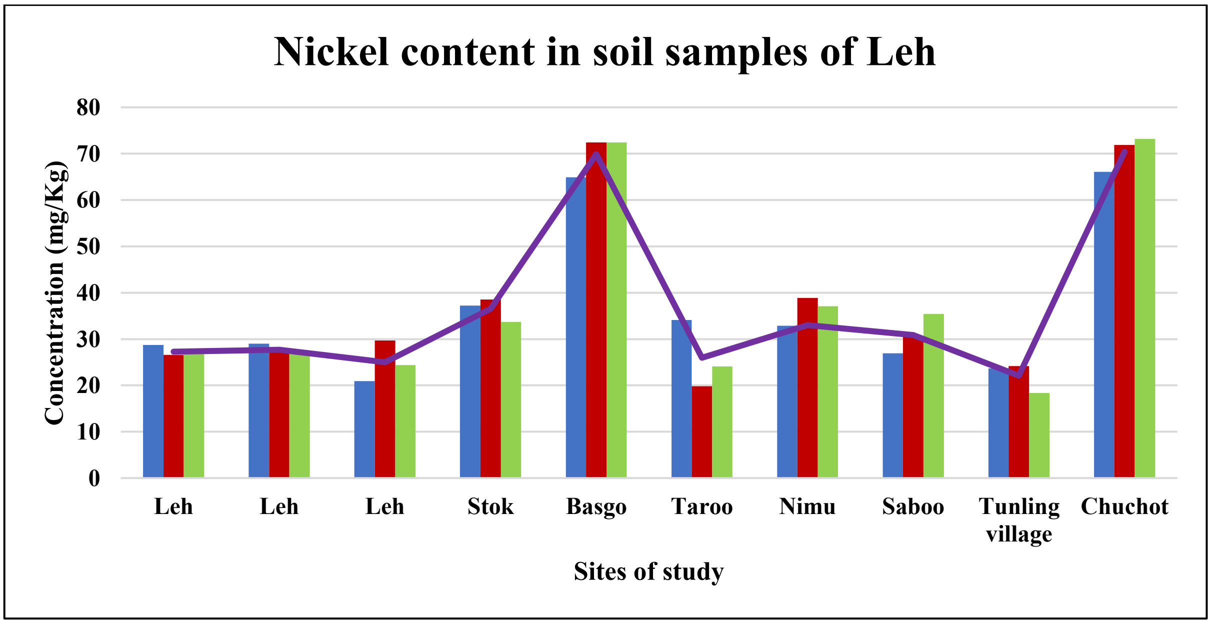

Fig 4.13: Concentration of nickel present in soil samples obtained from various study sites in Leh

The concentration of cobalt detected in this study varies from 13.6-28.9 mg/kg whereas the total mean value is 21.27 ±2.26 mg/kg. The highest concentration of cobalt present among the soil samples collected from various study sites was found to be 28.9 ±1.2 mg/kg in Basgo and the least concentration of cobalt present among the soil samples collected from these study sites was found to be 13.6 ±1.8 mg/kg in third sample from Leh.

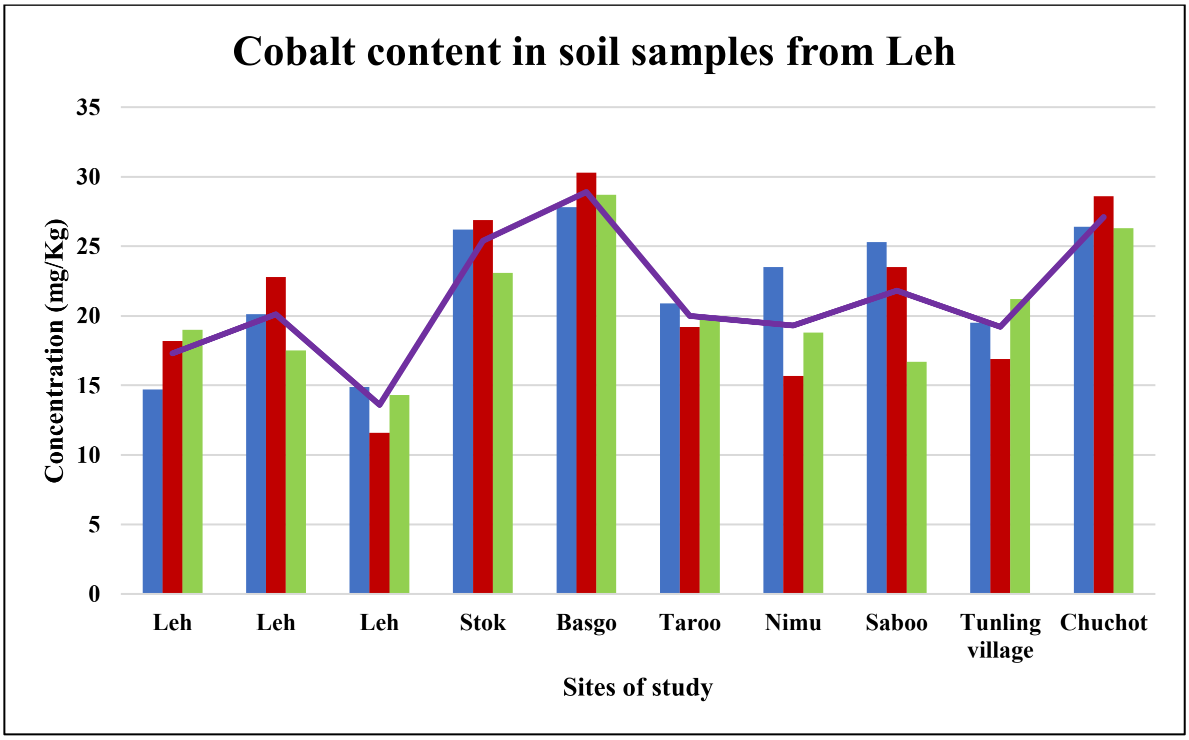

Fig 4.14: Concentration of cobalt present in soil samples obtained from various study sites in Leh

The concentration of chromium detected in this study varies from being absent to a concentration of 0.896 mg/kg whereas the total mean value is 0.154 ±0.048 mg/kg. The highest concentration of chromium present among the soil samples collected from various study sites was found to be 0.896 ±0.099 mg/kg in Nimu and chromium was found to be absent in all three Leh samples, Stok, Taroo, Saboo, Tunling village, Chuchot.

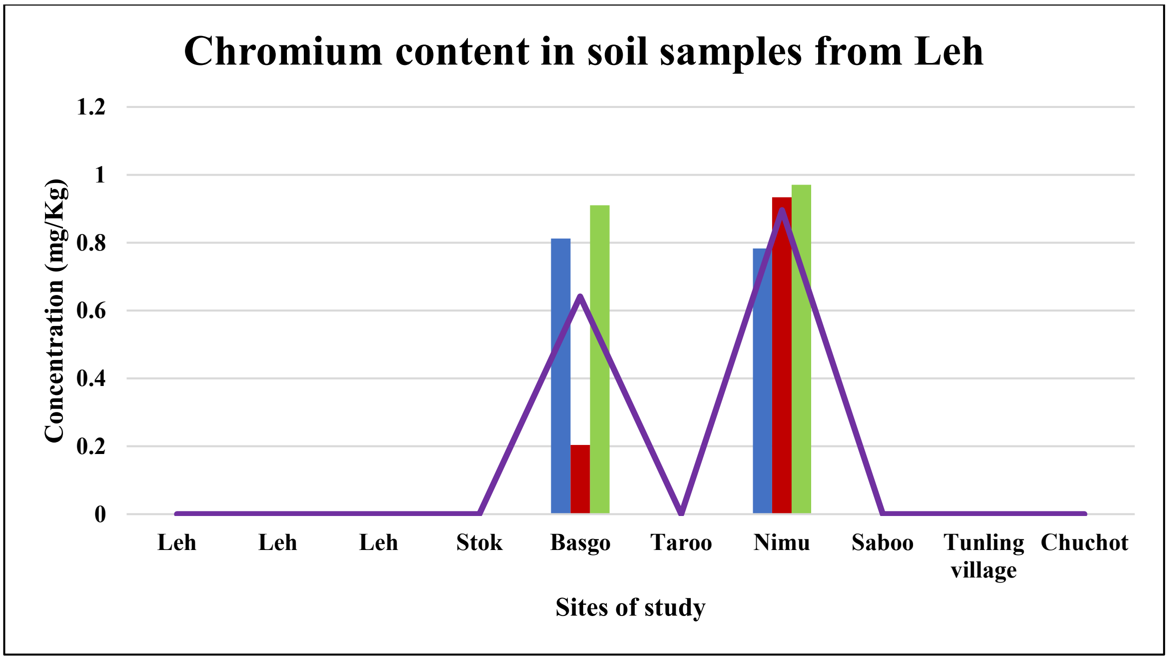

Fig 4.15: Concentration of chromium present in soil samples obtained from various study sites in Leh

The concentration of zinc detected in this study varies from 42.9- 219.8 mg/kg whereas the total mean value is 81.87 ±2.47 mg/kg. The highest concentration of zinc present among the soil samples collected from various study sites was found to be 219.8 ±7.4 mg/kg in Basgo and the least concentration of zinc present among the soil samples collected from these study sites was found to be 42.9 ±0.2 mg/kg in Tunling village.

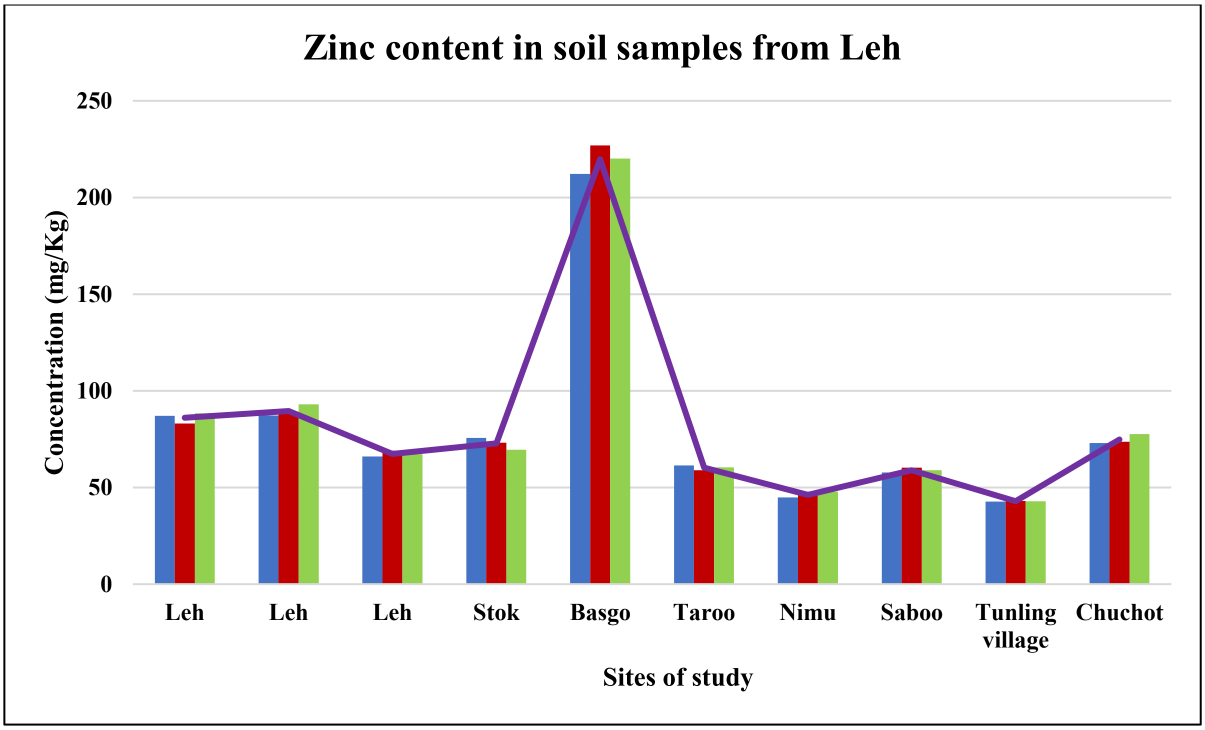

Fig 4.16: Concentration of zinc present in soil samples obtained from various study sites in Leh

Table 4.4: Heavy metal concentration in soil from various study sites of Leh

Soil Sample	Study Site	Altitude	Cu (mg/kg)	Ni (mg/kg)	Co (mg/kg)	Zn (mg/kg)	Cr (mg/kg)
Wavelength	-	-	**324.75 nm**	**232.00 nm**	**240.73 nm**	**213.86 nm**	**357.87 nm**
WHO (mg/Kg)	-	-	**150**	**70**	**10**	**300**	**150**
USEPA (mg/Kg)	-	-	**63**	**420**	**50**	**120**	**120**
High Altitude Soil 1	Leh	3500 m	21.4 ± 1.5	27.3 ± 1.2	17.3 ± 2.3	86.1 ± 2.8	5.4 ± 21.0
High Altitude Soil 2	Leh	3500 m	25.2 ± 0.9	27.7 ± 1.1	20.1 ± 2.7	89.5 ± 3.1	Absent
High Altitude Soil 3	Leh	3500 m	19.8 ± 0.9	25.0 ± 4.5	13.6 ± 1.8	67.4 ± 1.6	Absent

High Altitude Soil 4	Stok	3497 m	56.3 ± 9.2	36.5 ± 2.5	25.4 ± 0.20	72.8 ± 3.1	Absent
High Altitude Soil 5	Basgo	3292 m	29.9 ± 2.5	69.9 ± 4.3	28.9 ± 1.2	219.8 ± 7.4	83.0 ± 18.9
High Altitude Soil 6	Taroo	3524 m	18.5 ±1.2	26.0 ± 7.3	20.0 ± 0.80	60.2 ± 1.3	Absent
High Altitude Soil 7	Nimu	3140 m	19.5 ± 1.2	33.0 ± 4.1	19.3 ± 3.9	46.2 ± 1.5	89.6 ± 9.9
High Altitude Soil 8	Saboo	3544 m	192.1 ± 2	30.9 ± 4.3	21.8 ± 4.5	59.0 ± 1.2	Absent
High Altitude Soil 9	Tunling village		43.1 ± 1.2	22.1 ± 3.2	19.2 ± 2.1	42.9 ± 0.20	Absent
High Altitude Soil 10	Chuchot	3267 m	163.2 ± 0.2	70.4 ± 3.8	27.1 ± 1.3	74.8 ± 2.5	Absent

4.5. Health risk assessment for non-carcinogenic risk factors

4.5.1. Estimated daily intake (EDI)

Table 4.6 presents the Estimated Daily Intake (EDI) values for each metal derived from the water samples, along with the cumulative EDI obtained by combining the individual EDI values of all metals from the water samples. The EDI values for Cu, Ni, Co, Zn, and Fe in the water samples were determined to be 2.4435×10^{-7}, 1.4333×10^{-7}, 1.1596×10^{-7}, 2.4724×10^{-7}, and 1.3059×10^{-7} mg/day, respectively. The descending order of the EDI values for each metal, resulting from the consumption of water at different study sites, is as follows: Zn > Cu > Ni > Fe > Co.

Table 4.5: Health risk assessment of heavy metals in water of Leh

Metal	C_M	F_{IR}	E_D	C_F	E_F	B_W	T_A	RfD	CSFo
Cu (mg/L)	0.061375	3	67	0.085	365	64.05	67*365	0.04	0
Ni (mg/L)	0.036	3	67	0.085	365	64.05	67*365	0.02	0.0085
Co (mg/L)	0.029125	3	67	0.085	365	64.05	67*365	0.0003	0.0025
Zn (mg/L)	0.0621	3	67	0.085	365	64.05	67*365	0.3	0
Fe (mg/L)	0.0328	3	67	0.085	365	64.05	67*365	0.7	0

EDI was calculated using equation (1) and the data in table 4.5. The calculated data is presented in table 4.6.

Table 4.6: Health risk assessment of heavy metals due to water in Leh

Metal	Estimated Daily Intake (EDI)	Total Hazard Quotient (THQ)	Cancer Risk (CR)
Cu (mg/L)	2.4435×10^{-7}	6.1088×10^{-6}	-
Ni (mg/L)	1.4333×10^{-7}	7.1665×10^{-6}	1.2183×10^{-9}
Co (mg/L)	1.1596×10^{-7}	3.8653×10^{-4}	2.899×10^{-10}
Zn (mg/L)	2.4724×10^{-7}	8.2413×10^{-7}	-
Fe (mg/L)	1.3059×10^{-7}	1.8656×10^{-7}	-
Total	-	Hazard Index (HI) = 4.0082×10^{-4}	Target Cancer Risk (TCR) = 1.5082×10^{-9}

4.5.2. Target Hazard quotient (THQ)

Using equation (2), the Target Hazard Quotient (THQ) was calculated, and the corresponding values for Cu, Ni, Co, Zn, and Fe in the water samples collected from the high-altitude cold desert region study sites are presented in Table 4.6. The THQ values for Cu, Ni, Co, Zn, and Fe were found to be 6.1088 x 10^{-6}, 7.1665 x 10^{-6}, 3.8653 x 10^{-4}, 8.2413 x 10^{-7}, and 1.8656 x 10^{-7}, respectively.

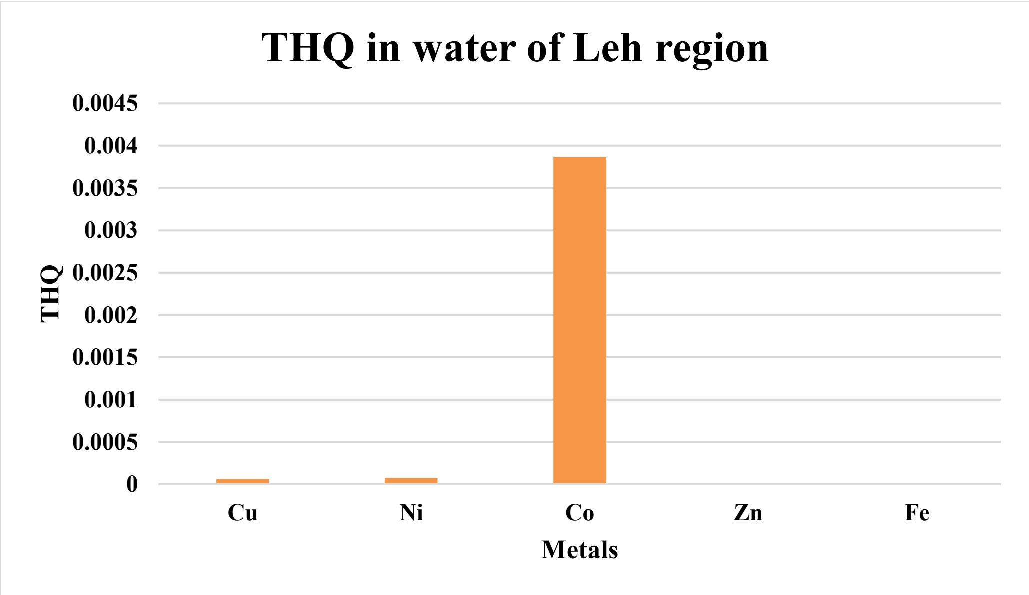

Fig 4.17: Graphical representation of THQ level of metals in water from high-altitude cold desert region

4.5.3. Hazard Index (HI)

The hazard Index is the total THQ of all the metals for the water samples from the study sites as shown in equation (3) and has a value of 4.0082 x 10^{-4}, which is less than the threshold level i.e., 1The metals were found to contribute to the overall risk in the following order: Co (96%) > Cu (2%) = Ni (2%) > Zn (0%) = Fe (0%).

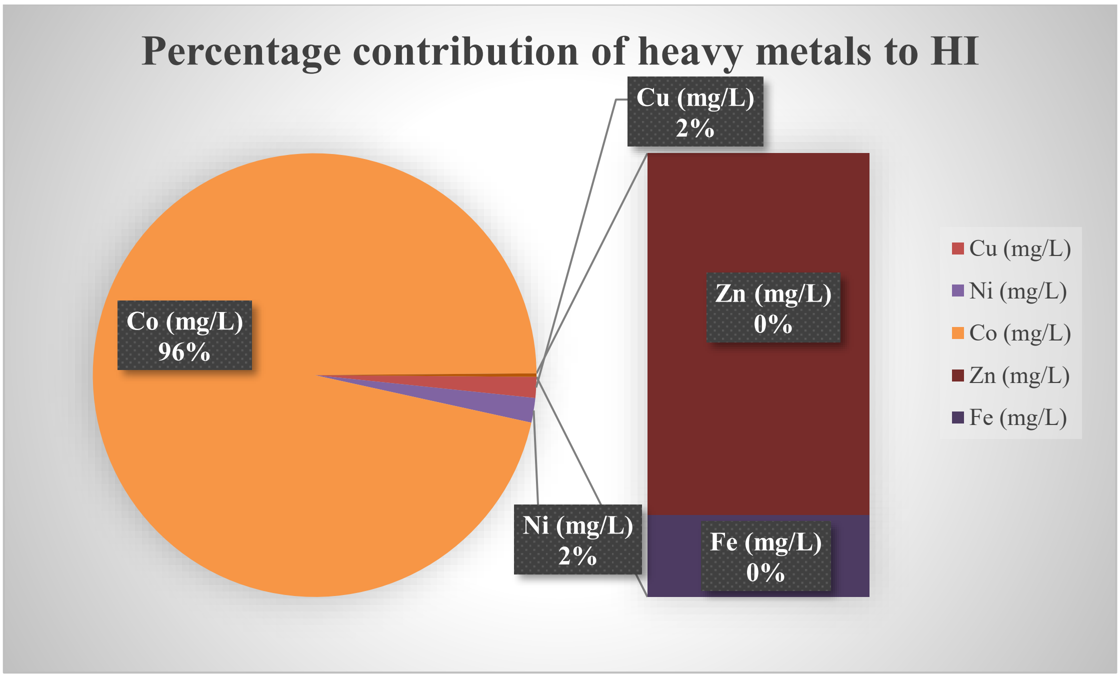

Fig 4.18: The total percentage contribution of heavy metals to hazard index (HI) of water from high-altitude cold desert region

4.6. Health risk assessments for carcinogenic risk factors

4.6.1. Cancer Risk (CR)

Cancer risk was computed using the CSFo. The value of CSFo was multiplied by EDI previously calculated and cancer risk was determined as shown in equation (4). Since CSFo of the metals analyzed was zero for Cu, Zn and Fe respectively, and the CSFo for Ni and Co was 0.0085 and 0.0025, respectively. The cancer risk (CR) calculated for Ni was 1.2183 x 10^{-9} and that of Co was calculated to be 2.899 x 10^{-10}. The Total cancer risk from all the metals in the water samples was calculated as shown in equation (5) and the value came out to be 1.5082 x 10^{-9}.

5. DISCUSSION

5.1. Levels of heavy metals present in water from Leh

5.1.1. Copper

The levels of copper found in water of Leh are all within the maximum permissible range according to WHO and EPA guidelines i.e., 2 mg/L and 1.3 mg/L but among these water samples Choglam tap water has the highest copper concentration being 0.269 ±0.01 mg/L. This water sample also has a very distinct and foul stench. Copper can be found in different forms and complexes in the environment, and its solubility depends on its particular form. While copper in food is usually bound to inorganic ligands or particles, the form of copper in water is different (Florence et al. 1992). Although the amount of copper in drinking water is generally low (Abedi Sarvestani and Aghasi 2019; Araya et al. 2001), human activities like mining and land use can release copper into the environment (Abedi Sarvestani and Aghasi 2019; Taylor et al. 2020). According to Ramesh et al. 2012, Cu concentrations in ground water of Tamil Nadu are an average of 0.0099 mg/L. According to Amangabara G. T. et al. 2012, Cu concentrations in ground water of Tamil Nadu are an average of 0.0015 mg/L. Whereas in Tanzania, Banzi F. P. et al., reported that Cu concentrations ranged between 2-17 µg/L. These concentrations of Cu were within the permissible limit in all of the above cases and thus do not pose a significant threat to humans since Cu is not a carcinogenic metal and has no CSFo value.

5.1.2. Nickel

The levels of nickel found in water of Leh are all over the maximum permissible range according to WHO but are within the permissible range according to EPA guidelines i.e., 0.02 mg/L and 0.1 mg/L, respectively but among these water samples Choglam tap water has the highest nickel concentration being 0.076 ±0.015 mg/L. This water sample also has a very distinct and foul stench. According to Ramesh et al. 2012, Ni concentrations in ground water of Nigeria are an average of 0.0014 mg/L. According to Charan G. et al., 2023, Ni concentrations in pond water of Leh are an average of 0.013 mg/L. Whereas in Tanzania, Banzi F. P. et al., reported that Ni concentrations ranged between 0.2-9.7 µg/L. Rehman K. et al., 2017, reported that Ni concentration in groundwater of Karachi ranges from 0.001-3.66 mg/L. Most of the above discussed water samples are within the permissible guidelines whereas Choglam water concentrations for Ni are over the permissible range according to the WHO guidelines and thus Choglam water samples need to be periodically assessed to ascertain the sources and concentration of heavy metals. The possible reason for rise in Ni in our study sites in Leh could also be the arsenic mining in Leh and the tailings left behind by this process similar to rise in Fe in Tanzania by Banzi F. P. et al. in case of uranium mining.

5.1.3. Cobalt

The levels of cobalt found in water of high-altitude cold desert region of Leh are all over the maximum permissible range according to WHO guidelines i.e., 0.01 mg/L except for one water sample among these which is Shey ground water with its cobalt concentration being 0.006±0.006 mg/L. The recommended daily intake for adults is roughly 2 µg, and Co can be found in a range of foods such as seafood, organ meats, leafy vegetables, and grains. Animal studies indicate potential carcinogenic effects of excessive cobalt intake, but no evidence supports cobalt's carcinogenicity in humans. (NIH, 2021). Whereas in Tanzania, Banzi F. P. et al., reported that Co concentrations ranged between 0.02-27.63 µg/L.

5.1.4. Zinc

The levels of zinc found in water of Leh are all within the maximum permissible range according to WHO and EPA guidelines i.e., 3.0 mg/L and 5.0 mg/L, respectively and is absent in few water samples namely Basgo spring water, Campus water ground/ tap, Choglam ground water, Nimu river water, Choglausal river water and Leh ground water. According to Ramesh et al. 2012, Zn concentrations in ground water of Tamil Nadu are an average of 0.0275 mg/L. According to Amangabara G. T. et al. 2012, Zn concentrations in ground water of Nigeria were an average of 0.016 mg/L. Whereas in Tanzania, Banzi F. P. et al., reported that Zn concentrations ranged between 2-62.94 µg/L.

5.1.5. Iron

The levels of iron found in water of Leh are all within the maximum permissible range according to WHO and EPA guidelines i.e., 0.3 mg/L each and is absent in one water sample that is Skara ground water. Numerous concerns may arise when there is a high concentration of iron in the water. It may cause aesthetically unpleasant problems, such as water that is undesirable for eating and domestic use due to a metallic taste and colouring. High iron levels in water can foster the development of iron bacteria. (USEPA; Minnesota Department of Health,2017). According to Amangabara G. T. et al. 2012, Fe concentrations in ground water of Nigeria are an average of 1.41 mg/L. Whereas in Tanzania, Banzi F. P. et al., reported that Fe concentrations ranged between 2-53890 µg/L. The rise in Fe concentration on this region could have been possibly due to Uranium mining project in a nearby region. This could have also been the source of increased TDS in both ground and surface water in the area. The possible reason for rise in metals in our study sites in Leh could also be the arsenic mining in Leh and the tailings left behind by this process.

5.2. Levels of heavy metals present in soil from Leh

5.2.1. Copper

The levels of copper found in soil of high-altitude cold desert region of Leh are almost all within the maximum permissible range according to WHO and EPA guidelines i.e., 150 mg/Kg and 63 mg/Kg but two of the soil samples among these soil samples collected from the survey study sites have excessively high copper concentration with values of 192.1±2 mg/Kg and 163.2±0.2 mg/Kg for Saboo and Chuchot, respectively. The Cu concentrations in urban soils of South Korea according to Lee H. G. et al., is 22.6-33.7 mg/Kg. Agho T. I. et al., 2021, reported 48.57 mg/Kg of Cu in dumpsite soils in Benin city, Nigeria. These dumpsites consist of a plethora of waste generated by anthropogenic activities, industries, rising population, etc similar to our study sites in Leh. Dasgupta R. et al., reported a range of 33- 42 ppm Cu in north-western Himalayas. Possible reasons for elevated levels of heavy metals in this otherwise geologically separated region of the country is due to the increasing diesel run vehicles along the Manali-Leh highway and other anthropogenic activities by the population there.

5.2.2. Nickel

The levels of nickel found in soil of Leh are all within the maximum permissible range according to WHO and EPA guidelines i.e., 70 mg/Kg and 420 mg/Kg but Chuchot is one of the soil samples among these soil samples collected from survey study sites which is almost on the borderline for WHO guidelines with the value of 70.4± 3.8 mg/Kg but is still well under the USEPA guidelines. Rehman K. et al., 2017, reported that Ni concentrations in Karachi in Malir river area are 74 mg/Kg whereas in areas known to be contaminated in Lahore Ni concentration is 324 mg/Kg. Tundup P. et al., 2017, reported Ni concentration in Ladakh to be an average 0.68 mg/Kg. The Ni concentrations in urban soils of South Korea according to Lee H. G. et al., is 13.7-20.5 mg/Kg. Agho T. I. et al., 2021, 41.25 mg/Kg of Ni in dumpsite soils in Benin city, Nigeria. The dumpsites contain a wide range of waste materials resulting from human activities, industrial operations, population growth, and other factors similar to our study sites in Leh. Dasgupta R. et al., reported aa range of 44-68 ppm Ni in north-western Himalayas. The elevated levels of heavy metals in this geologically isolated region can be attributed to the rise in diesel-powered vehicles on the Manali-Leh highway and other human activities carried out by the local population.

5.2.3. Cobalt

The levels of cobalt found in soil of Leh all exceed the maximum permissible range according to WHO guidelines but are within the maximum permissible range according to EPA guidelines i.e., 10 mg/Kg and 50 mg/Kg, respectively and Basgo is one of the soil samples among these soil samples collected from survey study sites which has the highest cobalt concentration with the value of 28.9± 1.2 mg/Kg but is still well under the USEPA guidelines. Dasgupta R. et al., reported a range of 12-20 ppm Co in north-western Himalayas. The presence of elevated levels of heavy metals in the Leh region, despite its geographical separation from other areas, can be attributed to anthropogenic factors such as the rising number of diesel-powered vehicles on the Manali-Leh highway and other human activities in the region.

5.2.4. Zinc

The levels of zinc found in soil of Leh are all within the maximum permissible range according to WHO and USEPA guidelines i.e., 300 mg/Kg and 120 mg/Kg, respectively but Basgo is the one and only soil sample among these soil samples collected from survey study sites which has the highest cobalt concentration with the value of 219.8± 7.4 mg/Kg and is within the range for WHO guidelines but exceeds the USEPA guidelines. The Zn concentrations in urban soils of South Korea according to Lee H. G. et al., is 93.6-158.9 mg/Kg. Agho T. I. et al., 2021, 142.93 mg/Kg of Zn in dumpsite soils in Benin city, Nigeria. Dasgupta R. et al., reported a range of 39- 129 ppm Zn in north-western Himalayas. The high levels of heavy metals observed in this geologically isolated region can likely be attributed to the rise in diesel-powered vehicles along the Manali-Leh highway and other human activities in the area.

5.2.5. Chromium

The levels of chromium found in soil of Leh are all within the maximum permissible range according to WHO and USEPA guidelines i.e., 150 mg/Kg and 120 mg/Kg, respectively and only Leh, Basgo and Nimu show presence of chromium in the soil samples collected from survey study sites whereas all other soil samples show an absence of chromium. Agho T. I. et al., 2021, reported 17.65 mg/Kg of Cr in dumpsite soils in Benin city, Nigeria. Dasgupta R. et al., reported aa range of 55-142 ppm Cr in north-western Himalayas. The presence of higher concentrations of heavy metals in this geologically isolated region could be attributed to various anthropogenic factors, including the growing number of diesel-powered vehicles on the Manali-Leh highway and other human activities carried out by the local population.

5.3. Health risk assessment of water for non-carcinogenic factors

5.3.1. Estimated Daily Intake (EDI)

The consumption of water contaminated with heavy metals had an impact on the well-being and health of the adult population in Leh, Ladakh, considering their average body weightThe daily intake of heavy metals was calculated by considering the metal concentrations in the water samples and the consumption rate, as described in equation (4). Upon evaluating the EDI values for all metals in water samples, it was determined that they were within the acceptable limit. Thus, it was established that the local population is currently not at an increased risk of experiencing elevated EDI levels for any of the heavy metals. Considering the adverse climatic conditions in the area, a greater intake of heavy metals through the EDI could have potentially posed a substantial health risk to the local population. According to Agho T. I. et al., 2021, the estimated daily intake was higher in children compared to adults and zinc was consumed the most. In another study by Adesuyi A. A. et al., 2021 in the wetlands of Lagos lagoon, Nigeria the average daily intake of the studied metals was reported to be more by children than by adults, 1.18×10^{-3} and 1.03×10^{-4}, respectively.

5.3.2. Target Hazard Quotient (THQ)

The non-carcinogenic risks associated with the build-up of heavy metals in the human body from consuming contaminated water were assessed using the Total Hazard Quotient (THQ). The concentrations of each metal in the water samples were found to be below the threshold level of 1. Therefore, it can be concluded that the adult population in the region is not exposed to any potential health risks associated with the specific heavy metals examined in this study. Cr had the highest THQ for adults and children, 1.11×10^{-2} and 8.57×10^{-2}, respectively as reported by Agho T. I. et al., 2021.

5.3.3. Hazard Index (HI)

The HI is a measure used to evaluate the accumulation of different metals in the body due to food intake or other pathways. In this particular study, all calculated HI values were found to be below the critical threshold of 1. When both the HQ and HI values are below 1, it indicates that there is no significant risk to the community. On the contrary, if HQ or HI values exceed 1, it suggests the possibility of non-carcinogenic hazards. Based on the obtained values for all non-carcinogenic parameters associated with metal exposure through water consumption in the Leh region, it can be concluded that the analysed water samples are deemed secure for human consumption. According to Agho T. I. et al., 2021, the HI for adults and children was 0.020002 and 0.166999, respectively.

5.4. Health risk assessment of water for carcinogenic factors

5.4.1. Cancer Risk (CR)

The CR was evaluated by multiplying the EDI with the CSFo measured in mg/kg/day. Among the heavy metals analyzed in the water samples, Ni and Co had a CSFo, allowing for the computation of their respective CR values. The CR value for Ni was determined to be 1.2183×10^{-9}, while the CR value for Co was calculated as 2.899×10^{-10}. The cumulative cancer risk arising from all the metals present in the water samples was determined to be 1.5082×10^{-9}, which falls within the acceptable range of 10^{-4}. However, it is crucial to note that prolonged and continuous exposure to these heavy metals in the future may potentially elevate the risk of cancer in the region. According to Agho T. I. et al., 2021, the lifetime cancer risk of the metals that were investigated was higher in children than in adults. In another study by Adesuyi A. A. et al., 2021 in the wetlands of Lagos lagoon, Nigeria the lifetime CR for children and adults were 1.68 x 10-5 and 1.02 x 10-5, respectively which were both within the threshold values.

6. CONCLUSION

The main aim of this study was to evaluate the drinking water quality in a particular area and determine any potential health hazards linked to its consumption. A total of 16 water samples were gathered, encompassing samples from rivers, springs, groundwater sources, and taps within the region. The samples underwent analysis to assess several factors such as pH, conductivity, resistivity, salinity, turbidity, and total dissolved solids (TDS).

The pH values of the water samples were within the acceptable range of 6.5 to 8.5, as recommended by the United States Environmental Protection Agency (USEPA) for drinking water. The conductance, which measures the water's conductivity, should ideally be below 500 µS/cm according to the World Health Organization (WHO) 2006 guidelines, indicating the absence of organic pollution. For TDS, which refers to the concentration of dissolved solids in water, a level of less than 500 mg/l is considered suitable for human consumption according to WHO. Similarly, the WHO suggests salinity levels in drinking water should be less than 600 mg/L. Turbidity, which measures the clarity of water, should be below 5 nephelometric turbidity units (NTU) according to WHO guidelines. However, there was one sample from the Choglam region that exceeded the permissible limit for conductance, TDS, salinity and turbidity. These elevated levels of conductance, salinity, resistivity, turbidity, and TDS may indicate a possibility of water contamination by heavy metals.

The study also analysed the average levels of heavy metals, including Cu, Co, Zn, Fe, and Ni, in the drinking water samples. The findings revealed that Ni concentrations exceeded the allowed threshold in all samples, except for two samples (campus water and Basgo river water). Co exceeded the limit in only two samples from the Nimu region, namely groundwater and river water. The mean concentration of other heavy metals tested fell within the permissible range or was absent in some samples. The mean concentrations of Cu, Co, Zn, Cr, and Ni in the soil samples generally fell within the permissible range according to WHO and USEPA standards, with the exception of Cu concentrations in Saboo and Chuchot samples.

The study also analysed soil samples from the region, revealing an alkaline pH ranging from 8.17 to 9.15, whereas the ideal permissible range is 7.79 to 8.54. The alkaline nature of the soil in Leh Ladakh is influenced by factors such as arid climate, high mineral content, and limited rainfall. Additionally, the sandy nature of the soil is due to the dry conditions of the semi-arid cold desert region.

The study provided baseline information on heavy metals in water samples from this high-altitude cold desert region of Leh. All health risk parameters, such as EDI, THQ, HI, CR, and cumulative CR, were found to be below the specified threshold level.

However, there were elevated concentrations of Ni and Co in most water samples. This raises concerns for long-term exposure, as these metals have carcinogenic properties and could potentially lead to cancer in residents of the study region. When water contaminated with these heavy metals is used for irrigation of crops and fodder, it can transfer these metals into the food chain, affecting ecosystems and potentially leading to bioaccumulation in animals.

Overexposure to nickel can cause immunotoxic, neurotoxic, genotoxic, hepatotoxic effects, and cancers of the lungs, throat, and stomach, among other health issues. Cobalt overexposure may result in nausea, vomiting, lack of appetite, respiratory diseases, goiter, nerve damage, and damage to the heart and kidneys.

To summarize, this study highlights the importance of assessing the quality of drinking water in the region of Leh, identifying potential health risks associated with heavy metal contamination, and the potential transfer of these metals through the food chain.

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