Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan

Mr. Kinley Dorjee

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Public Health in Public Health
COLLEGE OF PUBLIC HEALTH SCIENCES
Chulalongkorn University
Academic Year 2022

การประเมินความเสี่ยงผลกระทบต่อสุขภาพ จากโลหะหนักในฝุ่นริมถนน
ใกล้พื้นที่ก่อสร้างเขื่อนไฟฟ้าพลังน้ำ เมืองวังดีโพดรัง ประเทศภูฏาน

นายคินเลย์ ดอร์จี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาสาธารณสุขศาสตรมหาบัณฑิต
สาขาวิชาสาธารณสุขศาสตร์ ไม่สังกัดภาควิชา/เทียบเท่า
วิทยาลัยวิทยาศาสตร์สาธารณสุข จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2565

Thesis Title	Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan
By	Mr. Kinley Dorjee
Field of Study	Public Health
Thesis Advisor	Assistant Professor Pokkate Wongsasuluk, Ph.D.

Accepted by the COLLEGE OF PUBLIC HEALTH SCIENCES, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Public Health

.... Dean of the COLLEGE OF PUBLIC HEALTH SCIENCES
(Professor CHITLADA AREESANTICHAI, Ph.D.)

THESIS COMMITTEE

.... Chairman
(Associate Professor WATTASIT SIRIWONG, Ph.D.)

.... Thesis Advisor
(Assistant Professor Pokkate Wongsasuluk, Ph.D.)

.... Examiner
(Professor Mark G. Robson)

คินเลย์ ดอร์จี : การประเมินความเสี่ยงผลกระทบต่อสุขภาพ จากโลหะหนักในฝุ่นริมถนน ใกล้พื้นที่ก่อสร้างเขื่อนไฟฟ้าพลังน้ำ เมืองวังดีโพดรัง ประเทศภูฏาน. (Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan) อ.ที่ปรึกษาหลัก : ปกเกศ วงศาสุลักษณ์

ปัญหาฝุ่นปนเปื้อนโลหะหนักและผลกระทบต่อสุขภาพของมนุษย์นั้นจัดเป็นปัญหาที่ทั่วโลกตระหนักในช่วงทศวรรษที่ผ่านมา การสัมผัสกับฝุ่นละอองริมถนนนั้นสามารถก่อให้เกิดปัญหาสุขภาพทั้งผลกระทบแบบเฉียบพลันและเรื้อรัง ประเทศภูฏานเป็นหนึ่งในประเทศที่กำลังเผชิญกับปัญหาสุขภาพ ที่เป็นผลกระทบจากสิ่งแวดล้อมเช่นกัน เนื่องจากการเพิ่มขึ้นของกิจกรรมของมนุษย์และการพัฒนาประเทศ เช่น การสร้างเขื่อนไฟฟ้าพลังน้ำ เป็นต้น การศึกษานี้จึงมีวัตถุประสงค์เพื่อวิเคราะห์ความเข้มข้นของโลหะหนักในฝุ่นริมถนน ในบริเวณใกล้เคียงพื้นที่ก่อสร้างเขื่อนไฟฟ้าพลังน้ำ และเพื่อประเมินความเสี่ยงผลกระทบต่อสุขภาพที่ไม่ใช่มะเร็งและมะเร็ง จากการหายใจเอาฝุ่นปนเปื้อนโลหะหนักเข้าไป การศึกษานี้เป็นการศึกษาแบบภาคตัดขวาง โดยเก็บตัวอย่างฝุ่นริมถนน จากบริเวณใกล้เคียงพื้นที่ก่อสร้างเขื่อนไฟฟ้าพลังน้ำในเมืองวังดีโพดรัง ประเทศภูฏาน และวิเคราะห์ As, Pb, Cr และ Hg ที่ปนเปื้อนในฝุ่น ด้วย ICP-OES รวมถึงการเก็บข้อมูลประชากรที่อาศัยในพื้นที่ศึกษา ผ่านการสัมภาษณ์ด้วยแบบสอบถาม จากผลการศึกษาพบว่าค่าเฉลี่ยความเข้มข้นของโลหะหนักในตัวอย่างฝุ่น Cd-4±0.00, $4.7 \times 10^{-4} \pm 6.7 \times 10^{-4}$, $6.5 \times 10^{-1} \pm 1.16$, 5.16±5.90 และ 15.71±5.58 mg/kg ตามลำดับ โดยโลหะหนักที่พบนั้นมีค่าความเข้มข้นไม่เกินมาตรฐานความปลอดภัย ผลการประเมินความเสี่ยงผลกระทบต่อสุขภาพที่ไม่ใช่มะเร็ง พบว่า HQ เท่ากับ 3.66×10^{-7}, 1.21×10^{-3}, 2.67×10^{-6}, 9.27×10^{-10} และ 2.17×10^{-9} สำหรับ As, Cr, Cd, Hg และ Pb ตามลำดับ HI มีค่าเท่ากับ $1.22 \times 10^{-3} \pm 3.34 \times 10^{-4}$ ซึ่งอยู่ในระดับที่ยอมรับได้ <1 ส่วนผลการประเมินความเสี่ยงต่อมะเร็ง พบว่า ค่าเฉลี่ยของ As, Cr, Cd และ Pb คือ $1.09 \times 10^{-9} \pm 4.50 \times 10^{-10}$, $4.59 \times 10^{-9} \pm 1.26 \times 10^{-9}$, $6.88 \times 10^{-10} \pm 1.89 \times 10^{-10}$ และ $4.59 \times 10^{-12} \pm 1.26 \times 10^{-12}$ ตามลำดับ โดยค่าเฉลี่ยผลรวมความเสี่ยงต่อการเกิดมะเร็งทั้งหมดทุกโลหะหนักที่ศึกษา คือ $6.92 \times 10^{-9} \pm 1.90 \times 10^{-9}$ ซึ่งอยู่ในระดับที่ยอมรับได้เช่นกัน สรุปผลการศึกษา พบว่าไม่มีความเสี่ยงผลกระทบต่อสุขภาพจากการจากการหายใจเอาฝุ่นริมถนนที่ปนเปื้อนโลหะหนักเข้าไปในกลุ่มประชากรท้องถิ่นที่อาศัยอยู่ใกล้เคียงพื้นที่ก่อสร้างเขื่อนไฟฟ้าพลังน้ำในภูฏาน อย่างไรก็ตาม การศึกษานี้ขอแนะนำให้ผู้อยู่อาศัยในพื้นที่ ควรใช้หน้ากากอนามัยเพื่อป้องกันตนเองจากฝุ่นละอองริมถนนและป้องกันผลกระทบต่อด้านสุขภาพอื่นๆ นอกเหนือจากโลหะหนัก รวมถึงการดูแลและป้องกันฝุ่นที่อาจเพิ่มปริมาณมากขึ้นจากการก่อสร้างเขื่อนที่ยังคงดเนินการต่อเนื่องไปอีกนานอีกด้วย

สาขาวิชา	สาธารณสุขศาสตร์	ลายมือชื่อนิสิต	....
ปีการศึกษา	2565	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....

6574002653 : MAJOR PUBLIC HEALTH
KEYWORD: Heavy metals, Health risk assessment, dust, inhalation, Bhutan

Kinley Dorjee : Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan. Advisor: Asst. Prof. Pokkate Wongsasuluk, Ph.D.

The concern over the heavy metal laden dust and its impact on human health has gained global importance over the decade. Exposure to roadside dust is associated with various acute and chronic health issues. Bhutan too is battling environmental health issues due to increasing anthropogenic and developmental activities such as hydropower dam construction. This study analyses the heavy metals concentrations in roadside dust near hydropower dam construction areas and assesses the noncancer and cancer risk of exposure to heavy metals laden dust through inhalation. This study was a cross sectional study. The roadside dust samples near hydropower dam construction in Wangduephodrang District were collected and analyzed for As, Pb, Cr, and Hg concentration by using ICP-OES. The socio demographic data and exposure factors were collected through interviews. The mean concentration of the heavy metals in the dust samples were Cd<Hg<As<Pb<Cr at $<7.59x10^{-4}\pm0.00$, $4.7x10^{-4}\pm6.7x10^{-4}$, $6.5x10^{-1}\pm1.16$, 5.16 ± 5.90 and 15.71 ± 5.58 mg/kg respectively. All the concentrations of the heavy metals in the dust were lower than the permissible range for safety. The noncancer risk assessment showed that the HQ was $3.66x10^{-07}$, $1.21x10^{-3}$, $2.67x10^{-6}$, $9.27x10^{-10}$, and $2.17x10^{-09}$ for As, Cr, Cd, Hg and Pb. The HI was $1.22x10^{-03}\pm3.34x10^{-04}$, which indicates an acceptable risk at <1. The mean cancer risk of As, Cr, Cd and Pb was $1.09x10^{-09}\pm4.50x10^{-10}$, $4.59x10^{-9}\pm1.26x10^{-9}$, $6.88x10^{-10}\pm1.89x10^{-10}$ and $4.59x10^{-12}\pm1.26x10^{-12}$ respectively. The mean total cancer risk in the study area due to exposure to As, Cr, Cd and Pb was $6.92x10^{-9}\pm1.90x10^{-9}$, and lower than the acceptable range of $1.0x10^{-6}$. There is no potential non-carcinogenic and carcinogenic risk due to exposure to the heavy metals laden dust through inhalation in the hydropower dam construction areas in Bhutan. However, it’s recommended that residents should use face masks for self-protection from roadside dust and prevention of other adverse health effects apart from exposure to heavy metals under the study. Further dust suppression methods need to be strengthened in the area.

Field of Study:	Public Health	Student's Signature ....
Academic Year:	2022	Advisor's Signature ....

ACKNOWLEDGEMENTS

Words cannot express my gratitude to my advisor, Assistant Prof. Pokkate Wongsasuluk. Apart from her support as advisor in materializing this thesis, has guided me throughout my study period. I am mesmerized by the support received thus far. She has been a wonderful person, who has not only sailed me through the academic matter, but also guided me through the administrative requirements. This would never have been the same and possible without her support. I remain immensely grateful for the support and advice I have received thus far.

The crucial part of this thesis was laboratory analysis of the dust samples. Despite the immense work pressure, Mr. Adeep Monger, and Mr. Vishal Chhetri, RCDC has dedicated their time and effort for successful completion of the research. I would also like to thank Mr. Chimi Dorji, Chief Laboratory Officer, for your guidance and support as well. My heartfelt gratitude also extends out to Prof. Mark and Assoc. Prof. Wattasit for their valuable time and advice. I also owe my gratitude to Mr.Tashi Penjor, Chief Planning Officer, Ministry of health for his advice and support throughout this journey.

The learning adventure over the past one year has been graciously support by the Thailand International Cooperation Agency (TICA). This would never have been possible without the financial support received thus far. I would also like to thank the Royal Government of Bhutan for having trust and confidence in me. Furthermore, I would also like to thank the World Health Organization and Royal Center for Disease Control for the immense support received for the analysis of the dust samples, which is the most important part of this thesis.

Finally, I would like to thank Mr. Kinley Gyeltshen for logistic arrangements and support during the data collection. I would also like to thank my parents and siblings for your gracious support and prayers. I also remain forever grateful to my family, friends and relatives, who never fails to motivate me.

Kinley Dorjee

TABLE OF CONTENTS

Page

List of Tables

Page

List of Figures

Page

List of Abbreviations

ADD	Average daily dose
As	Arsenic
AT	Averaging time
BW	Body weight
Cd	Cadmium
CDC	Centre for Disease Control
Cr	Chromium
Cu	Copper
ED	Exposure duration
EF	Exposure factor
Fe	Iron
Hg	Mercury
HI	Hazard Index
HQ	Hazard quotient
ICP-OES	Inductively coupled plasma Optical Emission Spectroscopy
IhR	Inhalation rate
IOC	Item Objective Congruence
LD 50	Lethal dose 50
LOAEL	Lowest-observed-adverse-effect level
LOD	Limits of Detection
MoH	Ministry of Health
Ni	Nickel
NOAEL	No-observed-adverse-effect level
Pb	Lead
PEF	Particle emission factor
RfD	Reference dose
USEPA	United States Environmental Protection Agency
Zn	Zinc

1. Chapter I Introduction

1.1. Heavy metals contamination in environment

Environmental pollution due to rapid urbanization, economic activities and anthropogenic activities has adversely affected the environment, resulting in deteriorated human health. The concern over the heavy metal laden dust and their impact on human health is increasing over the years due to its deleterious consequences on public health (Mitra et al., 2022).

The rapid development due to anthropogenic activities has led to increase in levels of heavy metals in the environment (Sultan et al., 2022). In the developing countries, the rapid urbanization and developmental activities are the major producers of the pollutants in the environment (Bai et al., 2009; Bhattacharya et al., 2019; Tomczyk, Wiatkowski, et al., 2022). The presence of heavy metals in the street and industrial dusts has been reported by numerous studies(Cheng et al., 2018; S. Yang et al., 2020; Zgłobicki et al., 2018). These heavy metals are prevalent in the areas with anthropogenic activities due to their various uses.

Heavy metals are used as preservatives in wood, piping, electroplating, roofing decoration, creation of alloys, cladding and even as constituents of the stainless steels(Ceballos et al., 2022). It is also evident that mining and other land use changes are causing heavy metal deposition and suspension in the dusts (both indoors and outdoors) (Goguitchaichvili & Bautista, 2023; X. Yang et al., 2022).

1.2. Impact of Heavy metals on Human health

Heavy metals are a cause of concern globally due to their characteristics such as non-degradable, highly toxic, longevity, and bioaccumulation ability (Briffa et al., 2020; Du et al., 2013). Some of these heavy metals such as Arsenic (As), Cadmium (Cd), Chromium (Cr),Nickel (Ni) and Lead (Pb) are known carcinogenic and has huge impact on the human health(Tan et al., 2016). The evidences around the world shows that the inhalation and ingestion of dust could lead to numerous serious health conditions such as cancers, chronic kidney diseases, hypertension, dermal lesions, peripheral neuropathy, and vascular diseases(Denny et al., 2022).

Heavy metals can be harmful to human health through various means. Heavy metals act as enzymic cofactors or inhibitors and thus support biochemical reaction (Witkowska et al., 2021). The metals such as mercury (Hg), lead (Pb), copper (Cu), cadmium (Cd), arsenic (As), chromium (Cr), thallium (TI), manganese (Mn), zinc (Zn), and nickel (Ni) has the tendency to displace metals from their natural binding sites causing toxicity(Wong et al., 2006; H. Zhang et al., 2010). The elements such As, Cd, Cr, Co, Pb, Ni, and Zn are the most common heavy metals potentially hazardous to human health(Wong et al., 2006). Many of these elements, even at a very low concentration are toxic and carcinogenic to human and can potentially exert deleterious health effects due to inhalation, ingestion, and dermal contact (Tchounwou et al., 2012). However, the toxicity of these heavy metals depends on the level of contamination and exposure route. The toxicity also differs according to the age, gender, genetic and nutritional status of the people.

1.3. Hydropower Dam construction and environmental pollution

Bhutan is witnessing a rapid growth in infrastructure such as urban infrastructure development, land use changes, mining and industrial development (The World Bank, 2020). The number of vehicles in the country has also increased by three folds in the last decade (Road Safety and transport Authority, 2022; Road Safety and Transport Authority, 2009). In recent decade Bhutan has geared towards construction of various hydropower dams across the country, which is the main energy source in the country (Asian Development Bank, 2010; The World Bank, 2019). large number of pollutants is emitted during the construction of infrastructure due to machinery, earthmoving and transportation of the excavated materials (Al-Swadi et al., 2022; Sultan et al., 2022). However, not many studies are conducted to evaluate the prevalence of heavy metals in these areas and their implications.

Studies also points out the presence of heavy metals in the rivers where there is increasing anthropogenic activities (Rai, 2021; Rai et al., 2019).) i et al., (2022) found heavy metals in the fish species (Schizothorax richardsonii (0.354 μg/g), Salmo trutta (0.240 μg/g) and Neolissochilus hexagonolepis (0.240 μg/g) in the rivers where the hydropower dams are constructed. However, the implications of presence of such heavy metals on public health were not reported and studied. The fishing in Punatshangchu is also restricted due to presence of foraging areas of White bellied heron, which is listed in the IUCN list of critically endangered bird species. Many of the farming community in this area are also not dependent on the river for irrigation and depend mainly on streams and spring water for irrigation and drinking water.

Bhutan is also known for its pristine environment and clean air. The use of personal protective equipment (PPE) such as masks is very low. Evidences suggests that even during the covid-19 outbreak, the prevalence of use of mask among students was only 22% (Wangchuk et al., 2023). Such evidence suggests that many people could be exposed to heavy metals through inhalation. Therefore, it could pose a grave threat to the health of the people living in the areas with heavy metal laden dust.

It's critical to assess the level of HM in dust in the community and conduct health risk assessment to prevent possible HM risks through inhalation of dust. Exposure to dust through inhalation is critical route due to direct exposure to dust in the community as well as low level of use of face masks. Therefore, this study aims to assess the presence of heavy metals in the dust near heavy construction areas and evaluate their public health implications such as cancer and non-cancer risk. This will provide clear context-based evidence regarding the intensity of heavy metal pollution in the hydro-power dam construction areas in Bhutan. This study will also help in designing evidence based programmatic interventions in the areas to prevent public health issues related to environmental pollution and thus mitigate the issues.

1.4. Research Question

- What are the concentrations of heavy metals (Arsenic (As), chromium (Cr), Lead (Pb), mercury (Hg), and Cadmium (Cd)) in the dust samples from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan?
- What are the cancer risk and non-cancer risk of the heavy metals (As, Cr, Pb, Hg and Cd) related to dust samples from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan?

1.5. General Objective

The study aims to assess the human health risk related to heavy metals (As, Cr, Pb, Hg and Cd) in dust from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan.

1.6. Specific Objectives

- To find the concentrations of heavy metals (As, Cr, Pb, Hg and Cd) in the dust samples from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan.
- To assess the cancer risk and non-cancer risk of the heavy metals (As, Cr, Pb, Hg and Cd) related to dust samples from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan.

1.7. Hypothesis

- There are heavy metals (As, Cr, Pb, Hg and Cd) contaminated in the dust samples from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan.
- There are cancer risk and non-cancer risk of the heavy metals related to dust samples from the communities near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan.

1.8. Conceptual Framework

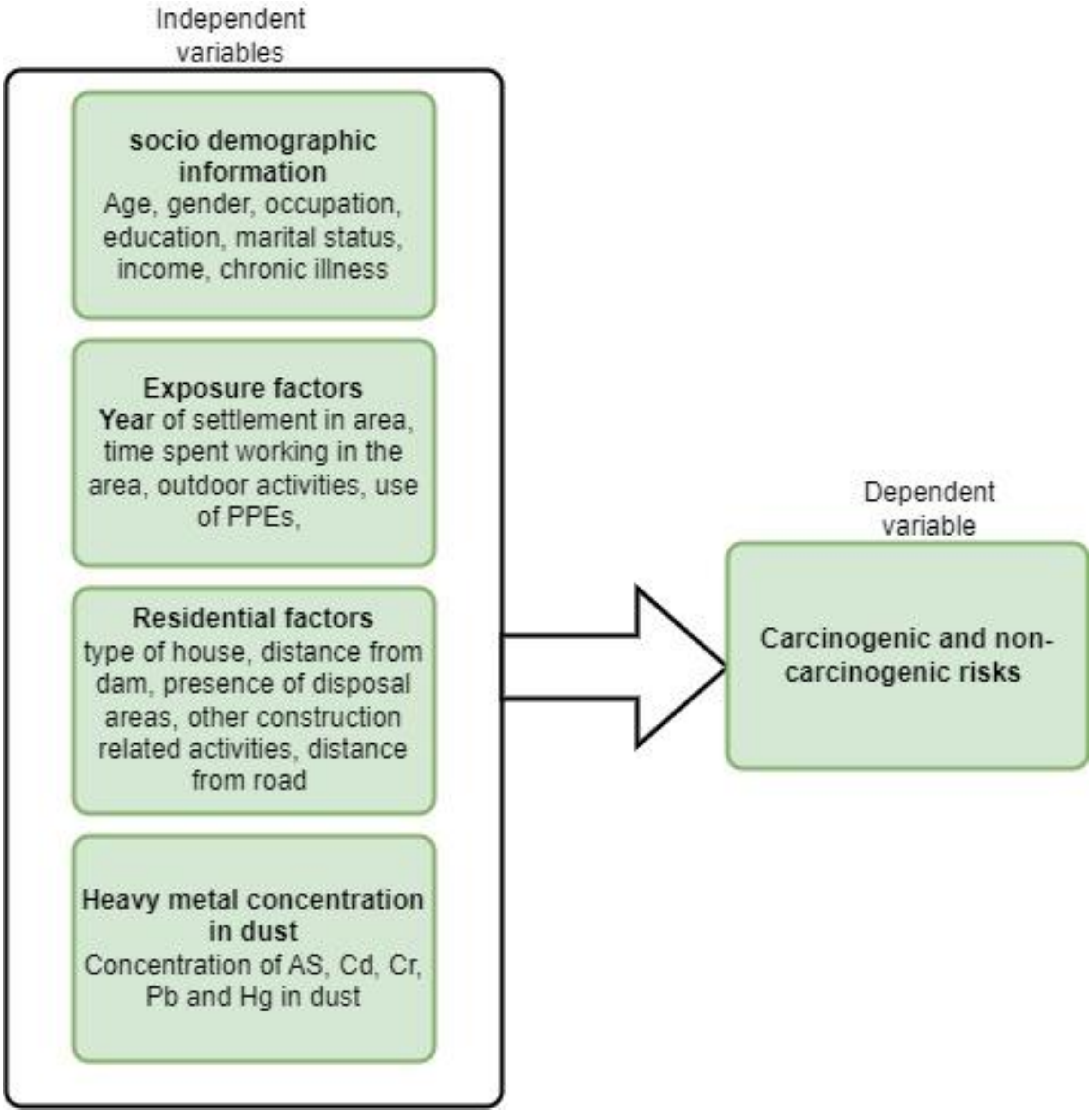

Figure 1 Conceptual framework of the study

1.9. Operational Definition

Table 1 The operational definition of the terms used in the study.

Cancer risk	Risk of developing cancer due to exposure to the heavy metals which has carcinogens
Health risk assessment	The process of estimating the risk of harmful health effects in humans due to exposure to the heavy metals in the dust.
Non-cancer risk	Noncancer risk refers to chance of noncancer harmful effects to human health resulting from exposure to heavy metal laden dust
Hazard quotient	A hazard quotient is the ratio of the potential exposure to a heavy metal and the level at which no adverse effects are expected
Hazard index	The sum of hazard quotients for the heavy metals detected in the study assuming that the effects of the different heavy metals are additive
Heavy metals	Heavy metals are a group of metals and metalloids that have a high atomic weight and density. In this study, heavy metals refer to the seven elements (As, Cd, Cr, Pb, and Hg) under study
Dust	The fine, dry powder of tiny particles settled on surfaces above ground level after being suspended in the air.
Non-essential Heavy metals	Metals/metalloids are those, which have no known biological function in living organisms
Essential heavy	Those heavy metals that have a biological role in the living

metals	systems
Anthropogenic activities	All the phenomena which can be consequent of the presence or the action of the human being
Household	“A household is defined as a person or group of persons, related or unrelated, who live together in the same dwelling unit, who acknowledge one adult male or female as the head of household, who share the same living arrangements, and are considered as one unit. A usual member is a person who “normally” lives in the household.” (PHCB, 2017 & NCD STEPS survey, 2019)
Usual Household members	A person who has lived with the household for at least 6 of the last 12 months (BLSS, 2017)
Chronic illness	Broadly defined as conditions that last 1 year or more and require ongoing medical attention or limit activities of daily living or both. Chronic diseases in the study includes cancer, COPD, and cognitive disability.
Roadside	The area within the 100mts buffer if Wangdue-Tsirang National highway between Wangduephodrang Bridge and Wangdue-Tsirang Border
Construction area	The Construction area in this study refers to the areas surrounding the construction of Punatsangchu I and II dams and related activities. The construction activities involve excavation of the area for Hydropower dam construction,

	involvement of heavy machineries and equipments, construction of houses and roads for workers, transportation and dump site for the excavated materials.
Hydropower dam	Hydropower dam in the study refers to the two Hydropower dams, namely Punatsangchu I and Piunatsangchu II which are under construction on the banks of Punatsangchu river (one of the major rivers in Bhutan)
Socio demographic characteristics	Socio-demographic characteristics are the general characteristics of the population in the area and include 1. Age, 2. Gender, 3. Occupation, 4. Education, 5. Marital status, 6. Income 7. Weight, 8. Height and 9. Chronic illness in this study.
Exposure factors	Factors that lead to human exposure to a toxic agent, describing its composition and size, as well as the type, magnitude, frequency, route, and duration of exposure
Residential factors	Factors related to the resident of the population such as, type of house, distance from construction area, distance from dam construction area, presence of disposal of residual materials from dam construction, workshops, and other metal works, which effects the rate of exposure of the individual to the pollution

2. Chapter II Literature Review

2.1 Heavy Metals

Heavy metals refers to metallic and metalloids with relatively high atomic weight and a density (five times greater than water) (Tchounwou et al., 2012). Many are required by the plants and animals in different quantities. Heavy metals can be categorized into essential and non-essential heavy metals based on their functions in human and plants (Saad et al., 2016). A trace amount of essential metals are vital to carry out fundamental structural and functional processes such as metabolism and health of plants and animals (Jyothi, 2020). The essential elements include iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), manganese (Mn), chromium (Cr), molybdenum (Mo), selenium, tin (Sn), nickel (Ni) and vanadium. Although they are not toxic at low concentration, they may induce harmful health impacts depending on the dosage and concentration(Mitra et al., 2022).

The non-essential metals include Arsenic (As), Lead (Pb), mercury (Hg), Aluminum (Al) and Cadmium (Cd). These heavy metals are not required by plants, even in trace amounts, for any of the metabolic processes. However, non-essential metal are capable of binding with the essential metal proteins and pathways, thus resembling the essential heavy metals in many ways (chemical and toxicological properties) (Slobodian et al., 2021).

2.2 **Road Dust and heavy metal concentration**

The resuspension of the solid particles generated from any anthropogenic activities and natural causes, primarily due to traffic movements and related activities along the road are known as road dusts. Road dust is the main pollutant in the industrial and cities (with high anthropogenic activities) and main source of PM 2.5. The particulate matter (PM) pollution in such areas mainly consists of resuspension of the road dust along with the wear and tear of the auto parts and road. However, the chemical composition of such re-suspended road dust depends on the silt deposited on the road due to different anthropogenic and natural activities prevalent in the area.

Numerous studies have found elevated presence of heavy metals in the dust. A study in mega city of Dhaka, Bangladesh found that the concentration of As, Cd, Cr, Pb, Ni, Zn and Cu were 1.564, 0.158, 40.780, 35.347, 21.542, 111.591 and 30.17 mg/kg respectively. Suryawanshi et al (2016) studied the industrial, highways and residential areas in Delhi, India. The study found that the concentration of Cd (1.9-3.8); Cr (56.4-500.3); Cu (87.3 - 499.0); Ni (27.2 to 61.7); Pb, (69.0-316.0), and Zn (187.7 -524.3) in the dust samples. Numerous other studies from China (Du et al., 2013; Han et al., 2017; H. Wang et al., 2021; X. Yang et al., 2022), Poland (Dytłow & Górka-Kostrubiec, 2021; Zgłobicki et al., 2018), Greece (Bourliva et al., 2012), and Nigeria (Mafuyai et al., 2015) also found similar presence of heavy metals in the roadside and urban street dusts.

2.3 **Health effects of heavy metals**

Health hazards associated with exposure to arsenic in dust include cancer, skin lesions, neurological effects, and respiratory (Bhattacharya et al., 2019)problems. Long-term exposure to inorganic arsenic has been linked to increased risk of lung, bladder, and skin cancer (US EPA, 1988). Skin contact with dust containing inorganic arsenic can lead to skin lesions such as hyperkeratosis and hyperpigmentation

(ATSDR, 2007). Neurological effects such as peripheral neuropathy and encephalopathy have also been reported in individuals exposed to inorganic arsenic. Respiratory problems, including chronic bronchitis and lung fibrosis, have also been associated with exposure to inorganic arsenic (IARC, 2012).

Long-term exposure to cadmium can lead to a variety of health hazards, including lung damage, kidney damage, and cancer. Inhaling high levels of cadmium dust and fumes can cause coughing, shortness of breath, and other respiratory problems (Genchi et al., 2020). Additionally, cadmium can accumulate in the body over time, leading to an increased risk of kidney damage and cancer. Furthermore, cadmium is also a known reproductive and developmental toxin (Tan et al., 2016). Exposure to the metal has been linked to decreased fertility, miscarriage, and birth defects. Children are also at a higher risk of health effects from cadmium exposure, as their developing bodies are more sensitive to the metal (Balali-Mood et al., 2021).

Lead exposure is well-documented and includes damage to the brain and nervous system, as well as an increased risk of various forms of cancer (World Health Organization (WHO), 2022). In addition, lead exposure has been linked to a variety of other health issues, including anemia, kidney damage, and reproductive problems (Balali-Mood et al., 2021).

When it comes to human health, exposure to mercury can have a wide range of negative effects. Long-term exposure to inorganic mercury, which is found in some industrial processes and pesticides, can lead to kidney damage (CDC, 2009). Exposure to metallic mercury, commonly found in dental fillings, can lead to neurological effects such as tremors, memory loss, and insomnia (ATSDR, 2022).

One of the most significant health hazards associated with mercury exposure is its potential to cause developmental delays and damage to the nervous system in fetuses and young children(Han et al., 2017).

2.4 Sources and routes of heavy metal

The major source of heavy metals in the dust is due to intensive anthropogenic activities(Abdel-Rahman, 2022; Armah et al., 2014). The developmental activities such as minning, construction and land use change releases heavy metals in the atmospheric air. However, no point source can be defined for heavy metal contamination of dusts as it’s a result of many sources contributing to the contamination. Humans can be exposed to heavy metal laden dusts through various pathways through inhalation, ingestion, and dermal contact (Abdel-Rahman, 2022; Al-Swadi et al., 2022; Briffa et al., 2020). The inhalation and ingestion of dust is known cause of numerous serious health conditions such as cancers, chronic kidney diseases, hypertension, dermal lesions, peripheral neuropathy, and vascular diseases (Denny et al., 2022).

Table 2 The detail description of each heavy metal studied with their health implications.

Heavy metal	**Physical and Chemical Properties**	**Sources in Environment**	**toxicity/possible effects**
Arsenic (As)	Atomic number, 33; relative atomic mass, 74.92 silver-gray/White metallic, odorless, brittle solid.	Treatment of wood (wood preservatives), Historic paintwork, pharmaceuticals, agricultural chemicals, mining, metallurgical, glassmaking, semiconductor industries, lead acid batteries, automotive solder, and radiators.	Carcinogenic hematotoxin, endocrine disrupter, Spontaneous abortions and still birth, possible teratogen

Heavy metal	Physical and Chemical Properties	Sources in Environment	toxicity/possible effects
Chromium (Cr)	Atomic number: 24, relative atomic mass: 51.99 steely-grey, lustrous, hard, and brittle transition metal, high resistance to oxidation and heat	Alloying material for steel, surface coating, metallic electroplating and cladding coatings, synthetic rubies, preservation of wood (CCA), tanning of leather, Refractory materials (heat-resistant applications), catalysts.	Carcinogenic, respiratory irritant, stomach irritant, anemia, sperm damage
Cadmium (Cd)	Atomic Number:48 soft, silvery-white divalent metal, corrosion resistant, insoluble in water, combines with other metals such as tin, copper, gold and silver to form mercury alloys known as amalgams	Used in nickel-cadmium batteries, electroplating (mainly in aircraft industry), prevention of corrosion of steel, coating, Anti-cancer drugs, photoconductive surface coating and in televisions, motion detectors, fluoresce microscopy, burning of fossil fuels such as coal or oil and the incineration of municipal waste, zinc, lead, or copper smelters, Smoking	Fetal malformations and other effects, pulmonary irritation, kidney diseases,
Lead (Pb)	Atomic number: 82, A dull, silvery-grey metal, corrosion resistance, density, and low melting point,	Paint, ceramics, pipes and plumbing materials, solders, gasoline, batteries, ammunition, and cosmetics	Affects the nervous system, kidney function, immune system, reproductive and developmental systems, and the cardiovascular system
Mercury (Hg)	Atomic number: 80 shiny and silver-white with a high surface tension, highly mobile and droplets combine easily due to low viscosity	Production of chlorine gas and caustic soda, and in thermometers, barometers, batteries, and electrical switches.	irritation to the eyes, skin, and stomach; cough, chest pain, or difficulty breathing, insomnia, irritability, indecision, headache, weakness or exhaustion, and weight loss, m neurological damage

2.5 Hydropower Dam construction and Environmental pollution

Hydro power dam construction is a crucial aspect of sustainable energy production, as it harnesses the energy of flowing water to generate electricity. However, the construction of hydropower dams can also result in the release of heavy metals into the surrounding environment(Chen et al., 2010; European Investment Bank, 2019). Heavy metal contamination in dust is a significant concern during hydro power dam construction, as it can have detrimental effects on human and the environment health (Bing et al., 2022; Tokmechi, 2011).

During hydro power dam construction, heavy metals can be released into the environment through various processes (Bing et al., 2019; Tokmechi, 2011). The construction of a dam can result in the removal of large amounts of soil and rock, which can release heavy metals that were previously trapped in the earth. Additionally, the use of heavy machinery and equipment can result in the release of dust containing heavy metals into the air. The construction of hydropower dams can also result in the release of heavy metals into nearby water sources, as the dams can block the natural flow of water and cause the build-up of sediment (Tokmechi, 2011).

The levels of heavy metal contamination in dust during hydro power dam construction. A study by Tomczyk et al. (2021) investigated the levels of heavy metal contamination in in the neighborhood of small hydropower plant in Poland. The study found that the composition of the heavy metals in the sediments were greatly affected by the hydropower plants. Studies have also found that the heavy metal concentration increases as we move downstream of the hydropower dams (Bai et al., 2009; Tomczyk, Gałka, et al., 2022).

Bhutan is known for its natural beauty, rich culture and tradition, and for being one of the few carbon-negative countries in the world (Yangka et al., 2019). However, the country's rapid development and rapid changes in landscape due to developmental activities propelled by population growth remain as major challenge in Bhutan (Sharma et al., 2021). Punatsang Chhu neighborhood has numerous sources of heavy metals in dust from related activities for construction of hydropower projects (PHPA I and II), construction activities, agricultural practices, traffic movements, sand dredging and riverine activities, and land use changes in the district. While there is limited studies conducted in the area to assess the heavy metal contamination in the neighborhood, a study by Tashi et al., (2022) found traces of heavy metals in the fishes in Punatsangchu, where the two major dams are under construction. The hydropower Dam construction projects have also led to increased anthropogenic activities and built-up environment in these areas.

2.6 Characteristics of selected heavy metals under study

2.6.1 Arsenic

Arsenic is a toxic heavy metal that can be found in various forms, including inorganic and organic compounds (L. Zhang et al., 2020). Dust can be inhaled, ingested, or absorbed through skin, making it a significant route of exposure for individuals. The arsenic released in environment has low mobility due to its high binding properties with soil (ATSDR, 2007).

The United States Environmental Protection Agency (EPA) has established a Reference Dose (RfD) for inorganic arsenic of 0.3 micrograms per kilogram of body weight per day (µg/kg-d) based on non-cancer effects (EPA, 2001). Additionally, the International Agency for Research on Cancer (IARC) has classified inorganic arsenic as a Group 1 carcinogen (IARC, 2012a). The median lethal dose (LD50) of inorganic arsenic is approximately 50-70 mg/kg in rats (Agency for Toxic Substances and

Disease Registry, 2018). Studies reported an increase in incidence of lung cancers due to long term exposure to 0.07mg/m^3(ATSDR, 2007).

2.6.2 Cadmium

Cadmium (Cd) is a non-essential HM which commonly found in the environment and highly mobile element (Kubier et al., 2019). It has the potential to accumulate in both the environment and human body for long periods (half-life of 25-30 years), leading to harmful health effects (Genchi et al., 2020). The properties such as corrosion resistant, low melting point and high conductivity makes it suitable for use in industries(IARC, 2012b). It is also used in a variety of industrial applications, such as in the production of batteries, pigments, and metal coatings. The main sources of cadmium exposure for humans is through ingestion of contaminated food and water and inhalation of dust and fumes containing the cadmium (Genchi et al., 2020). Cadmium can enter the environment through industrial and agricultural activities, leading to contamination of soil and water.

The chronic exposure to cadmium is known to compete with the calcium and other nutrients and thus causes liver and kidney dysfunctions as they are extremely sensitive to cadmium’s toxic effects (Genchi et al., 2020). The severe cadmium exposure causes *itai-itai*, which was first detected in 1960’s in Japan (Kubier et al., 2019). It also causes breast and lung cancer, cerebral infraction, and cardiac failure. The USEPA has classified cadmium as group-B carcinogen and the inhalation unit risk of 1.8X10-3 μg/m3(U.S. EPA, 1998).

2.6.3 Lead

Lead is a heavy metal that has been used in various industrial and consumer products for centuries(US EPA, 1997). However, the impact of lead on human health has become a significant concern in recent years (World Health Organization (WHO), 2022). According to CDC, around one third of the children globally have elevated blood lead (>5 µg/dL)(CDC, 2022).

One of the main sources of lead in the environment was from the use of lead gasoline in the past. However, due to its significant contribution to lead pollution, it’s phased out in many countries. Despite this, lead can still be found in the environment today, particularly in areas with a history of heavy industrial activity or mining (Jonasson & Afshari, 2018). Another leading source of lead is mining and processing of metal ore (Singh & Li, 2014). The dust and debris generated by these activities can release lead into the air, water, and soil, increasing the risk of exposure for people living in or near these areas.

Lead exposure can occur through several different routes, including inhalation, ingestion, and skin contact (Jonasson & Afshari, 2018). Dust containing lead can be found in and around homes and buildings, due to its common use in paints, water pipes, toys, and jewelry. Soil can also be a source of lead exposure, especially in areas with a history of heavy industrial activity or mining (Singh & Li, 2014). The median oral lethal dose (LD50) for lead is around 450 mg/kg of body weight and IDLH of 100 mg Pb/m^3. The permissible exposure limit (PEL) of lead is 0.050 mg/m^3(NOISH, 1994).

2.6.4 Mercury

Mercury is a naturally occurring element that can be found in different forms, including elemental, inorganic, and organic(CDC, 2009). The global emission of Hg was approximately 2390 mg and has grown by 1.8% per year over the last decade (Streets et al., 2019). While organic mercury in the environment is released through environmental conversions, elemental and inorganic mercury is released mainly through natural and human activities. One of the primary sources of mercury in the environment (elemental mercury) is from natural deposits, such as volcanic eruptions and weathering of rocks. However, human activities, such as mining, fuel combustion, waste incineration, coal-fired power plants and industrial processes, also contribute to the release of mercury into the environment (WHO, 2021).

Hg is a toxic substance that can have a significant impact on human health with no physiological role in Human (WHO, 2021). The exposure to Hg mainly effects neurological and renal systems causing issues such as vision, nerve conduction and cognitive dysfunction, and subjective physiological symptoms (ATSDR, 2022). The inhalation RfC of mercury is 3E-4 and LOAEL of 0.025 mg/m^3(US EPA, 1988b).

2.6.5 Chromium

Chromium (Cr) is abundant in nature with approximate concentration of <1.0E-4 mg/m3 in air. It is also found in the rocks and mainly deposited in the form of elemental or trivalent oxidation form. The Cr concentration in the soil ranges from 2 to 60 mg/kg (WHO, 1998). The reference concentration of chronic exposure to Cr particulates is 1E-4mg/m^3 and LOAEL of 2E-3mg/m^3(US EPA, 1998). The chronic exposure to Cr is known to cause lung cancer and the its association has been studied in many epidemiological studies (US EPA, 1998). Other effects of Cr includes asthma, pulmonary congestion and other respiratory diseases, edema, dermatitis and skin diseases (OSHA, 2006).

3 Chapter III Research Methodology

3.1 Study area and setting

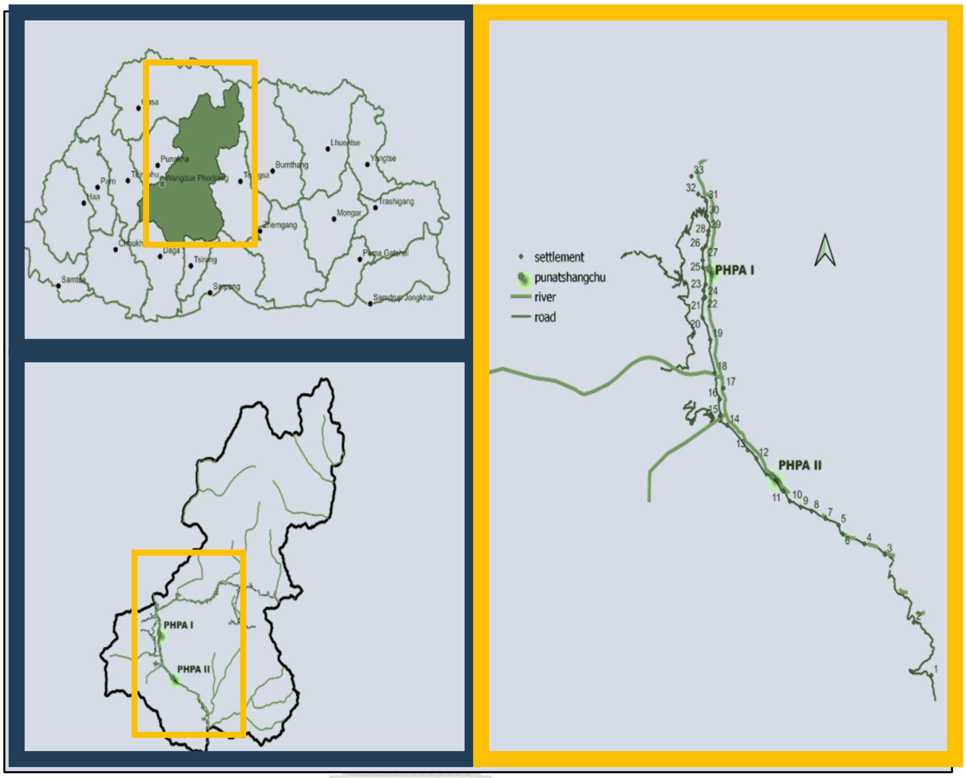

Figure 2: Map showing the study area.

Punatshangchu River flows through Wangduephodrang district (27.4879° N, 89.8996° E). The river is one of the major rivers in Bhutan and enters West Bengal in India. Catchment area of almost 9900 km2. The construction of first hydropower dam on the banks began in 2008 (Punatshangchhu-I) and the Dam site is about 7 km downstream of Wangdue Bridge (27.421388 N, 89.9047 E) and all other project components are located on the left bank of the river between 7 km and 21 km downstream of the Wangdue Bridge. The construction of Punatshangchu-II commenced in 2010. The diversion Dam of Punatsangchhu-II Hydroelectric Project (PHEP-II) is located about 20 km downstream of Wangduephodrang Bridge. All other project components are situated on the right bank. Its underground Powerhouse is 15 km downstream of Dam at Kamechu, Dagar Gewog.

Figure 3 Settlement and types of houses along the road in the study area

3.2 Methodology

This is a cross-sectional study. The level of HM in the area was assessed through dust samples and questionnaire-based interviews were conducted to assess the exposure risk.

3.1.1 Study population, sampling, and sample size

As per the Annual Household Survey, the total number of households in the study area is estimated to be 150 including huts and shops in the area (AHS, 2019). The total population of the area (usual Household members) is 320 people excluding the foreign expats and non-Bhutanese labors (. The sample size for the survey is calculated using Yamane formula for sample size calculation.

$$n = \left[\frac{N}{1 + N(e)^2}\right]$$

Where,

n-total number of samples required.

N: total population

e-acceptable sampling error

Using the above formula, the total sample required for the exposure assessment questionnaire interview was ;

$$n = \frac{320}{1 + 320(0.05)^2}$$

$$= 232.09$$

$\approx$ 233 respondents.

Since the average household size of Bhutan is 4 (NSB, 2018), a total of 63 household were selected using simple random sampling. All the individuals within the selected households fulfilling the inclusion criteria were interviewed.

3.1.2 Inclusion criteria

- Household within 100mts from the road
- Household members who lived in the area for more than 6 months of the last 12 months
- All individuals aged 20-65 were included in the study.

3.1.3 Exclusion criteria

- Non-Bhutanese individuals (including the labors) working in the area.
- Those who moved out and resettled recently in the area (less than 6 months)
- Has severe illness (clinically diagnosed) such as cancer, TB, cognitive disability, and COPD.

3.3 Research Instrument

The socio-demographic information including residential setting and the exposure information was collected using an interviewer administered questionnaire. The informed consent was sought from the participants before the interview. The interviewers were trained in the data collection procedure and methods. The interview responses were entered collected using epi-collect software and imported to the statistical tool for analysis.

3.3.1 Validity and Reliability

The questionnaire was reviewed and rated by three experts (1 from college of public health science and 2 from Ministry of Health, Bhutan). The validity of the questionnaire was assessed using Item-Objective Congruence (IOC). The contents of the questionnaire with IOC less than 0.5 was revised accordingly and presented for confirmation. The final IOC of the questions was above 0.677.

Table 3 reliability test of questionnaire

Total Items	**18**
Sum of Individual question variances	5
Total variance	0.473
Cronbach alpha	0.9541 (excellent)

$$r_{kk} = \frac{k}{k-1} \times \left(1 - \frac{\sum s_i^2}{s_t^2}\right)$$

A pilot test of the questionnaire was conducted using 10 individuals from a separate community which doesn’t fall in the study area. Accordingly, Cronbach’s alpha coefficient was calculated to assess the reliability of the questionnaire. The Cronbach’s alpha coefficient must be at least ≥0.7, which according to George and Mallery (2010) represents acceptable reliability.

3.3.2 Participant recruitment and Data collection methods

A total of 3 enumerators with prior experience in surveys were recruited for collection of social-demographic data. The enumerators were trained thoroughly on the processes of the study, information sheet and informed consent and the questionnaires. The road was buffered by 100mts and all the households within the boundary were line listed. From the line listed households, a total of 250 households were selected randomly using simple random sampling. All the members aged 18-65 were included in the study.

The interviewers visited each selected household and explained the details of the study as stated in the information sheet. The consent was sought from the participants.

3.4 Dust sample collection and analysis methods

3.4.1 Sampling and site selection for dust samples

The study was conducted along the Tsirang-wangdue highway areas which is along the right bank of Punatsang Chhu starting from Wangdue bridge to the Wangduephodrang and Tsirang confluence. The sampling sites for the dust were selected using Qgis. The road from Wangduephodrang Bridge to Tsirang-Wangdue junction was buffered by 100mts distance. 25 random points were selected with 150mts minimum distance between each point using Qgis.

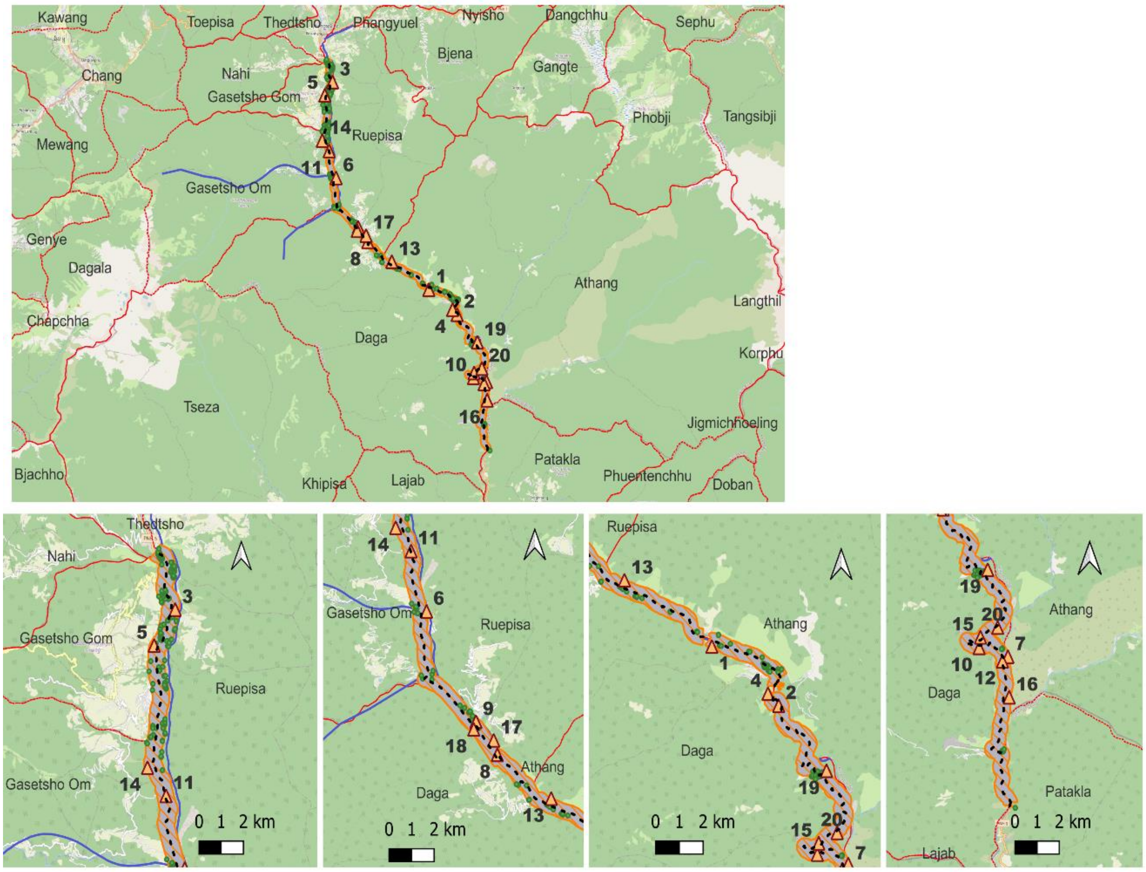

Figure 4 The study area showing the location of selected sites for dust sample.

3.4.2 Dust Sample collection

Settled dust samples were collected using natural bristle brush and stainless-steel dustpan from the plain surface such as window channels. The samples were collected from 25 different sites selected randomly (Fig.4). Three sub-samples (10grams each) were drawn from each sample site and mixed thoroughly to get the overall sample from the site. The collected samples were stored in zip log bags and stored in cooler box before transporting to the laboratory for analysis. All the samples were labeled with sample identification numbers. The samples were transported to the laboratory within 2 days of the date of collection of samples.

3.4.3 Sample preparation and analysis

For the determination of dissolved analytes in dust samples, first the samples were digested in microwave oven with the conditions as shown in table 1. A sample weight of 0.25 grams were digested with 5 ml of ultra-pure nitric acid and 2.5 ml of hydrogen peroxide and made the final volume of 50 ml with distilled water. The samples were filtered through a 0.22 µm pore diameter membrane filter of plastic filtering apparatus and analyzed using ICP-OES.

Commercially available standards were used for the analysis (Merck. USA). The chemicals and reagents used were of ICP-Trace metal grade of high purity. Multi-element standards (1000mg/ml) of lead, chromium, cadmium, arsenic, and mercury were used for analysis. Four levels of calibration standards were prepared ranging from 0. 0.l. 0.5 and 1 mg/L from a stock standard solution of 1000 mg/L. The correlation coefficient (R2) of the method determined was 0.99998 and the relative standard deviation were below the acceptable range of <2%.

Table 4 Microwave digestion condition

Parameters	Conditions
P11 (Bar)	40
T11 (°C)	195
Holding Time (seconds)	900

The measurement was performed using an Agilent 5110 ICP-OES instrument at Royal Center for Disease Control, Ministry of Health, Thimphu, Bhutan. The samples were analyzed based upon the US EPA method 200.7 on "determination of metals and trace elements in water and wastes by Inductively coupled plasma - atomic emission spectrometry". The wavelength used was 220.353 for Pb 214.439 for Cd, 267.7 16 for Cr and 188.980 for As. The method detection limits were 0.00084 mg/L as per the method followed.

3.5 Statistical analysis

All data sets were analyzed for homogeneity of variances test and normality test with Shapiro-Wilk test of normality. The mean metal concentration and standard deviations were calculated. The differences in the Heavy metal content by two different locations (Dam-I and Dam-II) were calculated using independent sample t-test. The statistical analysis was conducted using STATA software (version 17.0SE—Standard Edition, Statistics and Data Science, Copyright 1985-2021 StataCorp LLC, StataCorp, 4905 Lakeway Drive, College Station, Texas 77845 USA). The human health risk assessment was calculated following the US EPA's method for quantitative assessment of Human health risk.

3.6 Human health risk assessment (4 steps of risk assessment)

In this study, the human health risk to the participants exposed to heavy metals in this study area was calculated using the U.S EPA's four steps (hazard identification; dose–response assessment; exposure assessment; and risk characterization) for risk assessment. (USEPA - U.S, 2005)

3.6.1 Hazard identification

Hazard identification is the process of determining the potential incidences of adverse health effects whether exposure to a stressor can cause an increase in the incidence of specific disease due to the inhalation of the heavy metals in the dust. It assesses heavy metals and their causal association with health effects.

3.6.2 Dose-response assessment

Dose response relationship assess the association between amount of the heavy metals in the environment and exposure/contact with the stressor. In this study, the cancer slope factor (CSF) and inhalation reference dose (RfD) of heavy metals for the exposure route through inhalation (table 2) will be used in the evaluation of risks.

Table 5 slope factor and inhalation reference dose of the heavy metals studied.

Analyte	Slope factor	reference	Rfd	Reference
Arsenic	1.50E+01	(WSP Environment & Energy, 2010)	3.01E-04	(Nazarpour et al., 2018)
Chromium	4.2E+1	(WSP Environment & Energy, 2010)	2.20E-06	(WSP Environment & Energy, 2010)
Cadmium	6.30E+00	(WSP Environment & Energy, 2010)	1.00E-03	(X. Yang et al., 2022)
Lead	4.20E-02	(OEHHA, 2017)	3.52E-03	(X. Yang et al., 2022)
Mercury	-	-	8.60E-05	(WSP Environment & Energy, 2010)

3.6.3 Exposure assessment

Exposure assessment is "identification and evaluation of the human population exposed to a toxic agent, describing its composition and size, as well as the type, magnitude, frequency, route, and duration of exposure". (US EPA, 1992) The residents in the study area have the risk of being exposed to the heavy metals through inhalation during daily activities. Thus, the cancer and non-cancer risks of exposure to the heavy metals will be calculated by using;(ATSDR, 2020; US EPA, 1992; B. Wang et al., 2015)

$$ADD_{inh} = \frac{C_{dust} \times Inh_{rate} XEF \times ED}{PEF \times BW \times AT} \qquad (1)$$

Where;

ADD_{inh}: Average Daily Dose (exposure through inhalation; mg/Kg-day)

3.6.4 Risk Characterization

This is the final step in risk assessment, and it Integrates the results of hazard identification, dose response, and exposure assessments for the individuals(EPA, 1995). It evaluates the health risks posed by the exposure to heavy metals (individuals and populations) and describes the extent and severity of probable harm. It is assessed by comparing an estimated HM-specific air concentration to the Rfd for direct inhalation exposures which is known as hazard quotient (HQ)

Non-carcinogenic risk: the non-carcinogenic risk due to the exposure to the individuals will be calculated using.

$$Hazard\ quotient(HQi) = \frac{ADD_{inh}}{Rfd} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where;
ADD_{inh}: average daily dose through inhalation
Rfd: reference dose

Hazard quotient (HQ) shows the risks associated with health effects. The hazard index (HI) which is the sum of the HQs will be calculated using.

$$Hazard\ Index(HI) = \sum HQ_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where HQ_i is summation of the hazard quotient.

It's assumed that the effects of the different heavy metals are additive. The HI>1 indicates the potential adverse health risks while HI≤1 indicates no significant health risks.

Carcinogenic Risk Characterization

In this study, HM which is found to be carcinogenic will be considered during the assessment of cancer risks. The lifetime cancer risk posed by heavy metals via inhalation (CRinh) will be thus calculated using:

$$CR_{inh} = ADD_{inh} \times CSF \quad (4)$$

Where;
CR_{inh}: Cancer risk
CSF: Cancer Slope factor
ADD_{inh}: average daily dose through inhalation

The Total cancer risk will be calculated to see the overall risk of exposure to heavy metals.

$$TCRinh = \sum CRinh \quad (5)$$

The cancer risk will be classified as follows:

CR_{inh}	Risk classification
<1 × 10-6	No risk
≥1 × 10-6	Risk

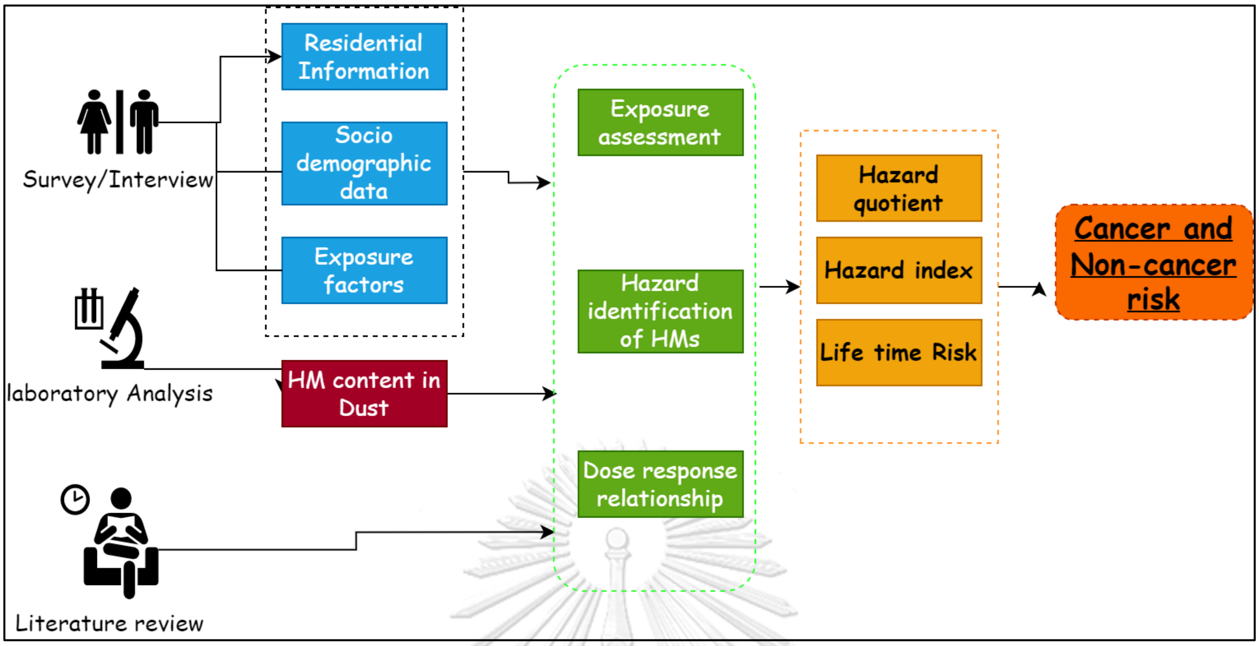

Figure 5 Research Flow chart

3.7 Research Timeline

	Dec	Jan	Feb	March	April	May	June	July
Proposal development								
Ethical clearance								
Data collection								
Data analysis								
Report writing								
Proceeding								
Final Exam								

3.8 Ethical clearance

The study was approved by Ministry of Health, Royal Government of Bhutan vide administrative clearance, MoH/PPD/ADM.CL/9/2023/033 dated 26/4/2023. Ethical approval for the study was obtained from Research Ethics Board of Health (REBH), Bhutan (ref no: REB/APPROVAL/09/2023/033, dated 20th May 2023).

4 CHAPTER IV RESULTS

This study was a cross sectional study conducted in Wangduephodrang district of Bhutan along the Wangdue-Tsirang national highway where two major hydropower dams are under construction. The socio-demographic and health status were collected using face to face interviews using structured questionnaire from 233 participants. This chapter provides a detailed description of results from the laboratory analysis of the dust samples for heavy metal contamination, the socio-demographic and health status of the participants and the cancer and non-cancer risk due to the exposure to heavy metals through inhalation.

4.1 Socio-demographic characteristics of the Participants

Among the 233 participants, majority of the participants were female (n:129; 55.36%). The mean age of the participant was 37±9.86; median:35 (percentiles:29-44) and ranges from 20-60. The mean age of the male participants was slightly higher ($\bar{X}$:37.53±9.72; median: 37) as compared to female ($\bar{X}$:36.68±9.72; median:35).

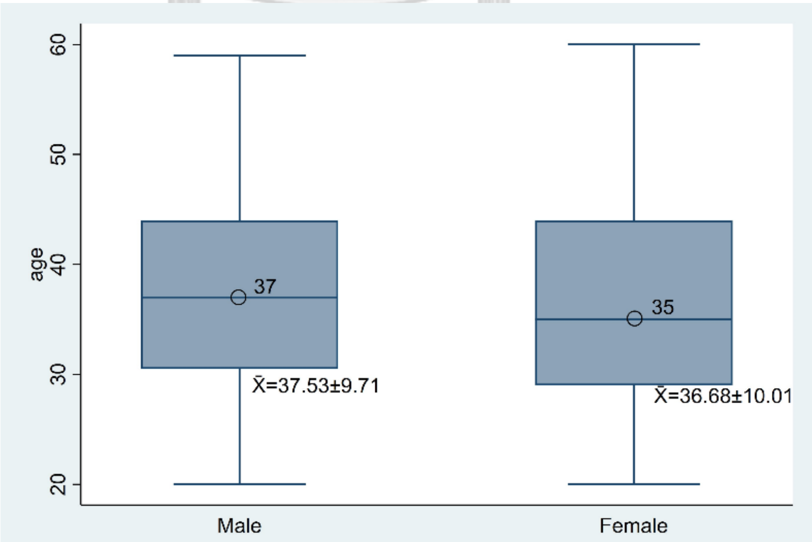

Figure 6: Age of participants by sex

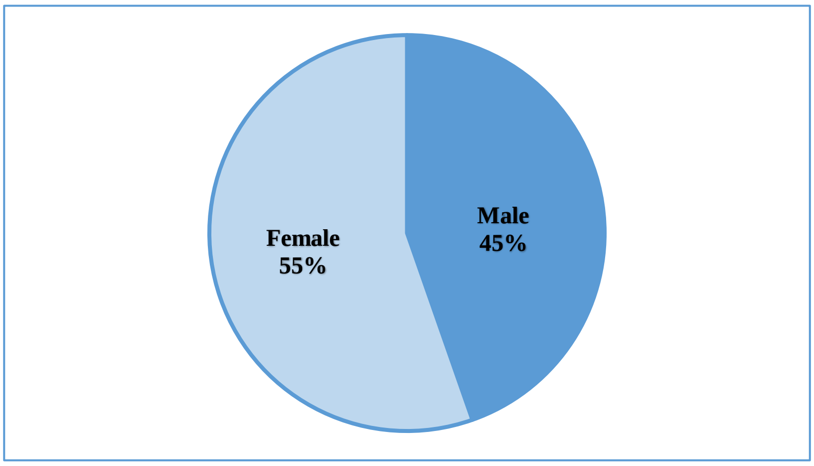

Figure 7 Proportion of participants by sex

The result also shows that 65.24% of the study participants are currently married. A total of 174 participants (74.68%) of the participants at least attended one form of formal schooling. Only 14.16% of the participants had a bachelor's degree or higher.

A higher number of participants were employed in the private sector including hydropower dam construction (inclusive of all categories of employment). A total of 88 participants (37.77%) were employed in this sector followed by the government/DHI/SOE sector (25.75%). At least 12% (n:28) participants in the study area depend on subsistence farming and 29 (12%) of the participants engaged in self-employment activities (mainly business).

Table 6 Socio-demographic characteristics of the study participants

	Sex					
	Male		Female		Total	
	n	%	n	%	n	%
Age (Years)	*$\bar{X}$:37±9.86; median:35 (29-44)*					
18-20	3	2.88	1	0.78	4	1.72
21-30	23	22.12	37	28.68	60	25.75
31-40	38	36.54	52	40.31	90	38.63
41-50	27	25.96	22	17.05	49	21.03
50+	13	12.50	17	13.18	30	12.88
Highest Level of Education Completed						
No Formal Schooling	18	17.31	29	22.48	47	20.17
Non-Formal Education	3	2.88	9	6.98	12	5.15

	Sex					
	Male		Female		Total	
Less Than Primary School	14	13.46	9	6.98	23	9.87
Primary Completed	10	9.62	8	6.20	18	7.73
Lower Secondary Completed	13	12.50	16	12.40	29	12.45
Middle Secondary Completed	13	12.50	21	16.28	34	14.59
High Secondary Completed	10	9.62	19	14.73	29	12.45
Certificate/Diploma	3	2.88	5	3.88	8	3.43
Bachelor’s Degree and Above	20	19.23	13	10.08	33	14.16
Marital Status						
Never Married	24	23.08	36	27.91	60	25.75
Currently Married	75	72.12	77	59.69	152	65.24
Separated	1	0.96	0	0.00	1	0.43
Divorced	4	3.85	8	6.20	12	5.15
Widowed	0	0.00	8	6.20	8	3.43
Main Work Status: Past 12 Months						
Government/DHI/SOE	19	18.27	15	11.63	34	14.59
Private Employee/Dam	42	40.38	46	35.66	88	37.77
Subsistence Farmer	13	12.50	15	11.63	28	12.02
Self-Employed	12	11.54	17	13.18	29	12.45
Student	8	7.69	11	8.53	19	8.15
Homemaker	1	0.96	22	17.05	23	9.87
Unemployed	6	5.77	2	1.55	8	3.43
Other	3	2.88	1	0.78	4	1.72
Household size						
≤2	29	27.88	28	21.71	57	24.46
3 To 5	20	19.23	20	15.50	40	17.17
More Than 5	15	14.42	17	13.18	32	13.73

4.2 Behavioral Characteristics of the study participants

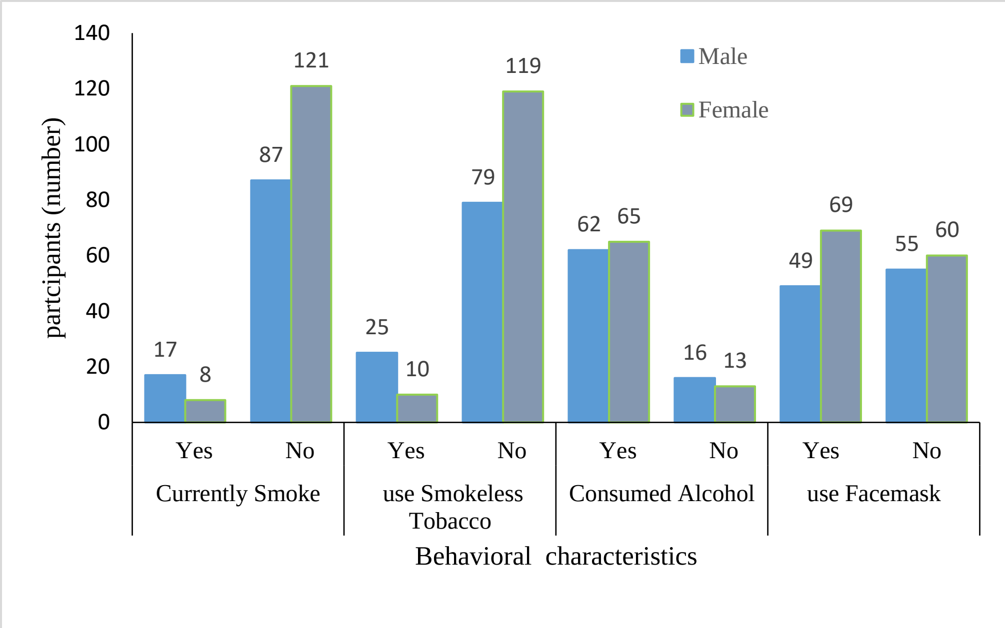

Figure 8 Behavioral characteristics of the study participants

The proportion of smokers among the study participant was higher among male (16.35%) as compared to female (6.20%). Similarly, the proportion of those who uses smokeless tobacco was also higher among male participants (n:25;24.20%) as compared to female. The alcohol consumption among male participant was 59.62% (n:65) with overall prevalence of alcohol consumption of 54.5% among the participants. The use of face masks is also practiced by almost 50% (n:118) of the study participants.

Table 7 Behavioral characteristics of the study participants

	Sex					
	Male		**Female**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**
Currently Smoke Any Tobacco Products						
Yes	17	16.35	8	6.20	25	10.73
No	87	83.65	121	93.80	208	89.27
Currently Use Any Smokeless Tobacco						
Yes	25	24.04	10	7.75	35	15.02
No	79	75.96	119	92.25	198	84.98

	Sex					
	Male		Female		Total	
	n	%	n	%	n	%
Consumed Alcohol: Past 12 Months						
Yes	62	59.62	65	50.39	127	54.51
No	16	15.38	13	10.08	29	12.45
Facemask						
Yes	49	47.12	69	53.49	118	50.64
No	55	52.88	60	46.51	115	49.36

4.3 Adverse health symptoms among the study participants

The exposure to heavy metals leads to various diseases (including cancer and non-cancer), and acute and chronic symptoms. Self-reported signs and symptoms, and diseases that could potentially be due to exposure to heavy metal laden dust were explored. The participants reported any signs and symptoms experienced during the

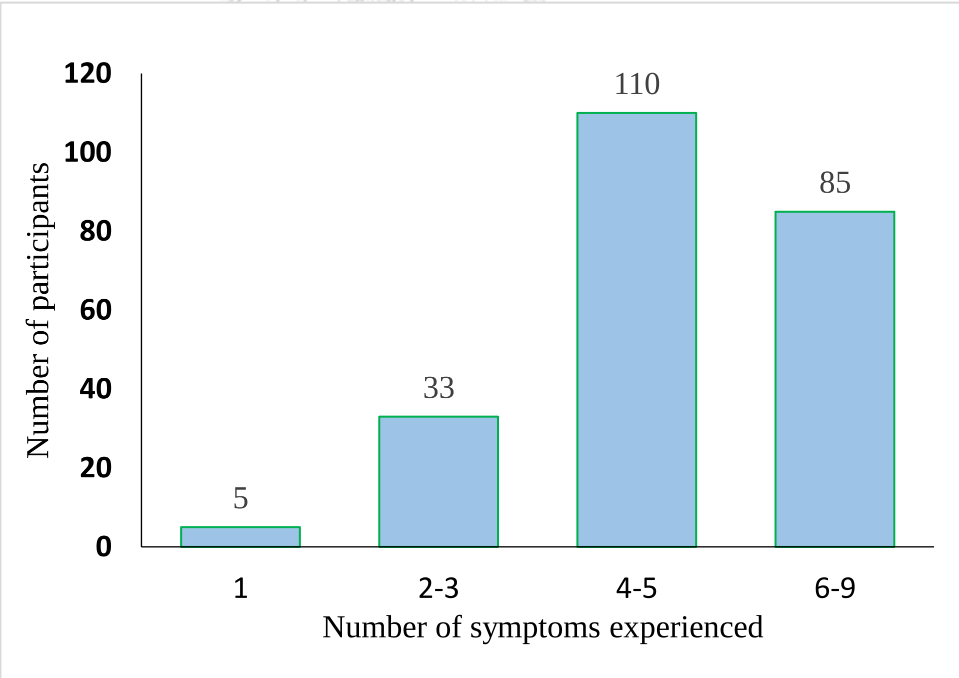

Figure 9 Number of different adverse health symptoms reported by participants.

past 12 months.

All the participants have at least experienced one of the symptoms in the past 12 months although most of the participants experienced 4 or 5 symptoms (n:110;

63.52%). None of the participants experienced all the symptoms. While there is no significant difference in number of participants experiencing the symptoms, a slightly higher number of participants had shortness of breath (n:129; 55.36%) and headache (n:126; 54.08%).

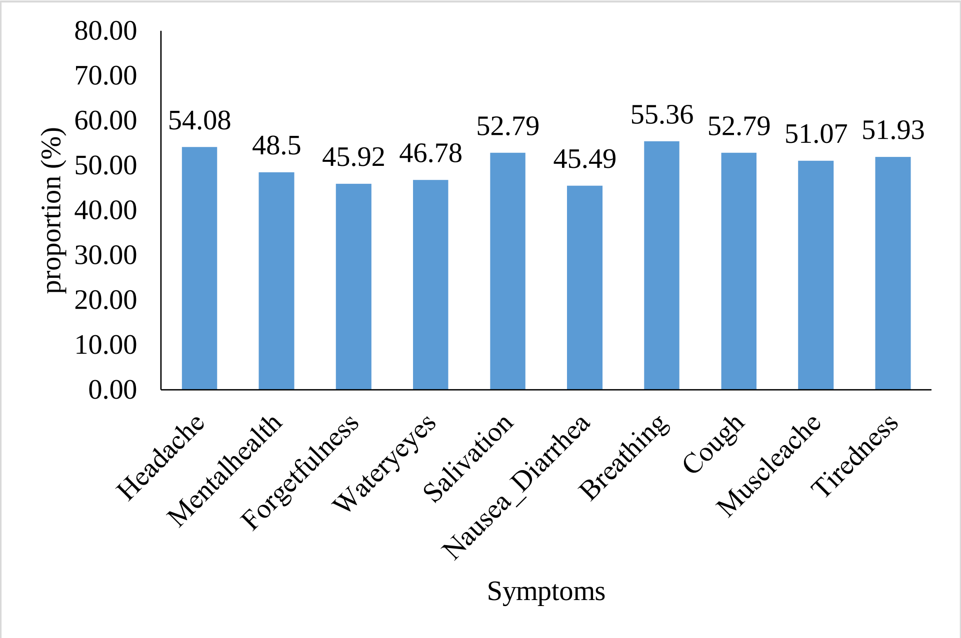

Figure 10 Proportion of participants reporting different symptoms

By gender, except for tiredness (male:51.24%; female:48.76%), majority of the participants who experienced different health symptoms were female in all other categories.

Table 8 Proportion of participants reporting different adverse symptoms.

Symptoms	**Sex**			
	Male		**Female**	
	n	**%**	**n**	**%**
Headache	57	45.24	69	54.76
Mental health	56	49.56	57	50.44
Forgetfulness	48	44.86	59	55.14
Watery eyes	50	45.87	59	54.13
Salivation	50	40.65	73	59.35

Symptoms	Sex			
	Male		**Female**	
	n	**%**	**n**	**%**
Nausea Diarrhea	52	49.06	54	50.94
Breathing	63	48.84	66	51.16
Cough	53	43.09	70	56.91
Muscle ache	56	47.06	63	52.94
Tiredness	62	51.24	59	48.76

4.4 Concentration of the heavy metals in road-side dusts

The concentrations of the heavy metal in the road-side dust samples from the study area are presented in table 8. The mean concentration of the heavy metals was in order of Cd<Hg<As<Pb<Cr.

Table 9 Concentration of Heavy metals in the study area

	Heavy metals (mgKg^{-1})				
	Mercury (Hg)	Lead (Pb)	Arsenic (As)	Chromium (Cr)	Cadmium (Cd)
Mean	0.00047	5.61	0.65	15.71	<0.000759
Std. dev.	0.00067	5.90	1.16	5.58	<0.000759
median	0.00010 (0-0.00067)	4.27 (2.63-5.54)	<0.0403 (0-1.31)	14.1 (12.1-18.0)	<0.000759
Min	<0.000014	0.73	<0.0403	8.00	<0.000759
Max	0.00235	28.55	5.16	27.76	<0.000759
LOD	0.000014	0.014412	0.0403	0.000668	0.000759
Guideline values*	0.50	60.00	5.00	100.00	1.00

**Threshold and guideline values for metals in soils (extract; MEF, 2007)*

The mean concentration of the Cr was 15.71±5.58mg/kg with median concentration of 14.1mg/kg (IQR 12.1-18).

The maximum concentration of Cr was 27.76mg/kg and was found near the hydropower dam I. Mann-Whitney U test showed a significant difference in the Cr

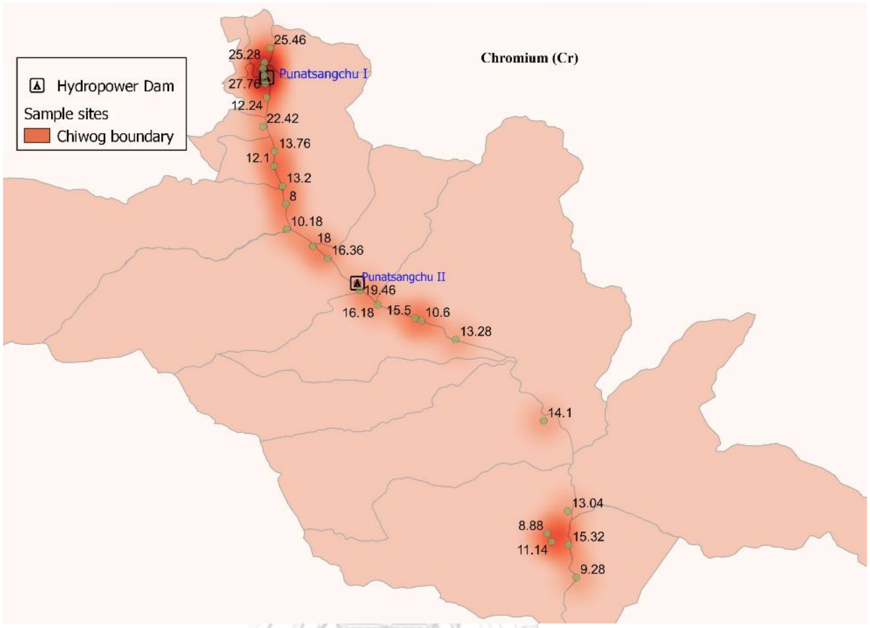

Figure 11: Chromium concentration in the study area

concentration between the samples closer to Dam I (M:19.36; SD:6.26) and Dam II (M: 13.29; SD: 3.51) at $t\ (23) = 3.1, p = 0.005$.

The mean concentration of Cr within 5km from dam was 18.30±5.62 and more than 5km was 11.83±2.43. The concentration of the Cr was higher near the dam and decreased as we moved further from the dam. There is a significant reduction in the Cr concentration as we move further from the dam at $r\ (24) = .\ -0.72, p = .006$.

The mean concentration of the As in the area was 0.65±1.16 mg/kg with median

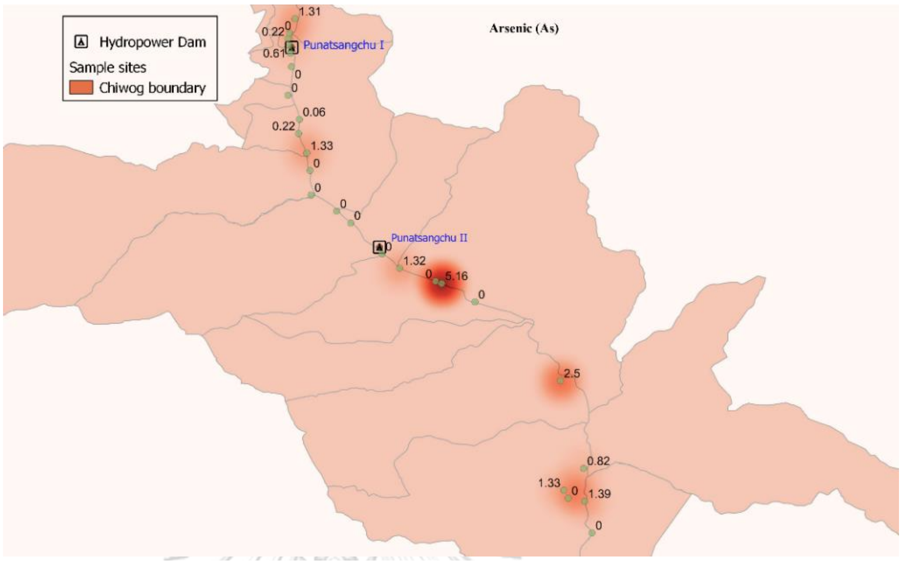

Figure 12 Arsenic concentration in the study area

concentration lower than 0.0403 mg/kg. The median concentration of As was less than LOD of 0.0403 (IQR: <0.043-1.31). The maximum concentration of As was 5.16. However, almost 50% of the samples had As concentration less than LOD. There is no statistical difference between the samples closer to Dam I and Dam II.

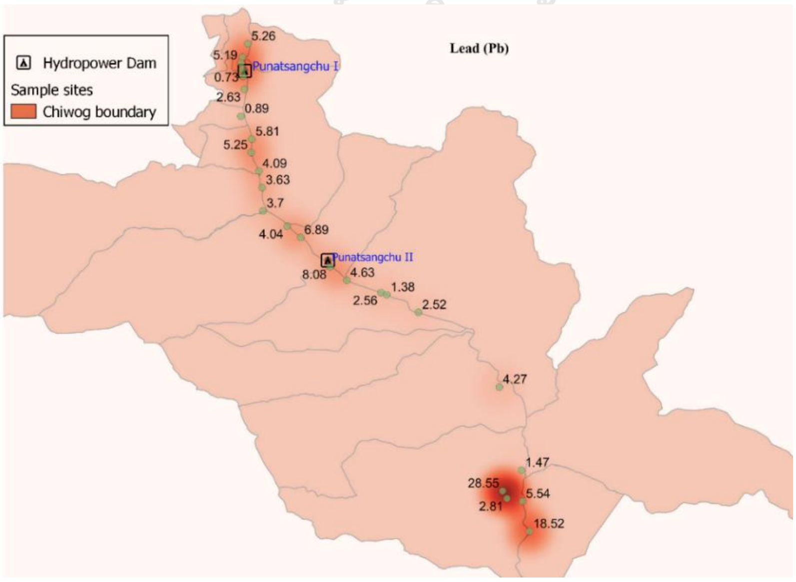

Figure 13 Lead concentration in the study area

Further, no statistically significant difference was observed between the concentration of As and distance from Dam.

The mean concentration of Pb was 5.61±5.90 with median concentration of 4.27mg/kg (IQR: 2.63-5.54). The highest concentration of Pb was 28.55mg/kg and was found 18km down stream of Dam II. There is no significant difference between the distance and the concentration of Pb (*P value>0.05*).

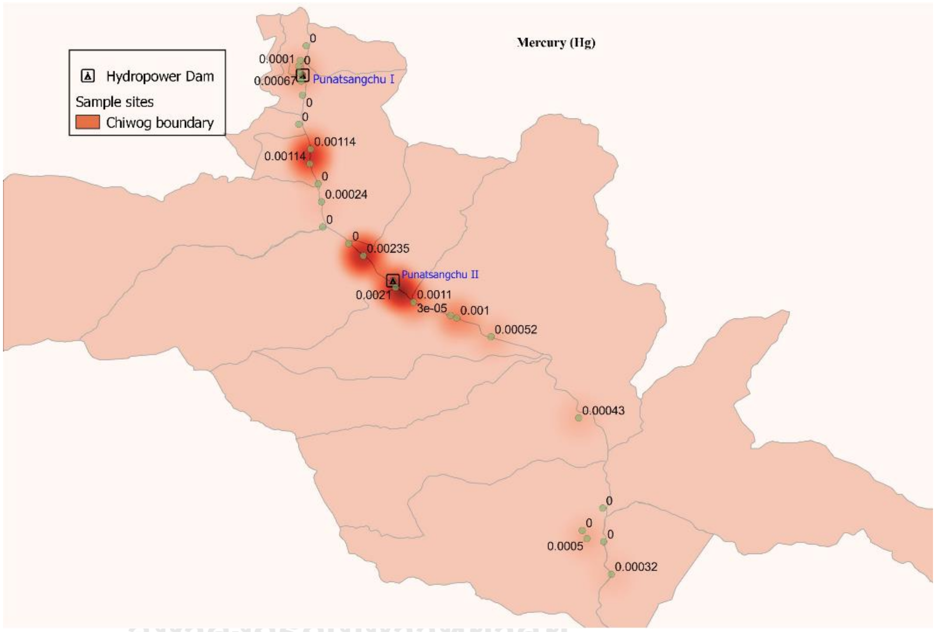

Figure 14 Mercury concentration in the study area

The mean concentration of Hg was 0.00047±0.00067mg/kg and median concentration of 0.0001 (IQR:<0.000014-0.00067). However, the concentration was lower than the LOD (0.000014) in nearly 45% of the samples. The highest concentration of Hg was 0.000662. No differences were observed in samples near Dam I and Dam II and there is no significant correlation between distance from Dam and concentration. The concentration of Cd was lower than the LOD (0.000759) in all the samples.

Table 10 mean differences in concentration of heavy metals among samples near dam I and dam II

	Dam1		Dam2			
	M	SD	M	SD	Z value	*p-value*
Chromium	19.356	6.26	13.29	3.51	2.22	0.03
Arsenic	0.38	0.17	0.83	1.42		*>0.05*
Cadmium						*>0.05*
Mercury	0.003	0.0004	0.0005	0.0008	-0.98	*>0.05*
Lead	4.16	2.09	6.57	7.37	0.00	*>0.05*

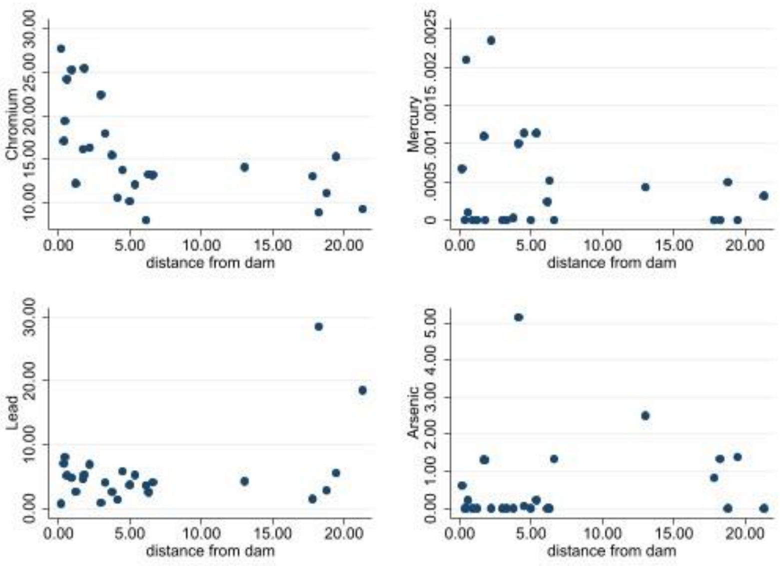

Figure 15: Correlation between concentration of heavy metals and distance from dam

4.5 Exposure assessment

The exposure factors such as age, body weight exposure duration was assessed through a questionnaire. The mean exposure frequency was 365 days per year. The mean years lived in the area was 14.49±16.94 years with minimum of 1 year and maximum of 60 years. However, the median years spent in the area was 8 years (4-12 years).

Table 11 Exposure factors

	Sex							
	Male				Female			
	Age (years)	weight (Kg)	Duration (years)	EF (days/year)	Age (years)	Weight (Kg)	Duration (years)	EF (days/year)
Mean	37.53	66.89	15.91	365	36.68	59.31	13.33	365
SD	9.71	11.99	18.32		10.01	11.47	15.71	
Median	37	65.9	8		35	57.1	8	
25th percentile	30.5	58.05	4		29	51.6	4	
75th percentile	44	74.5	12		44	64	12	
Min-Max	20-59	41.4-96.1	1-60	365	20-60	34.8-103.5	1-60	365

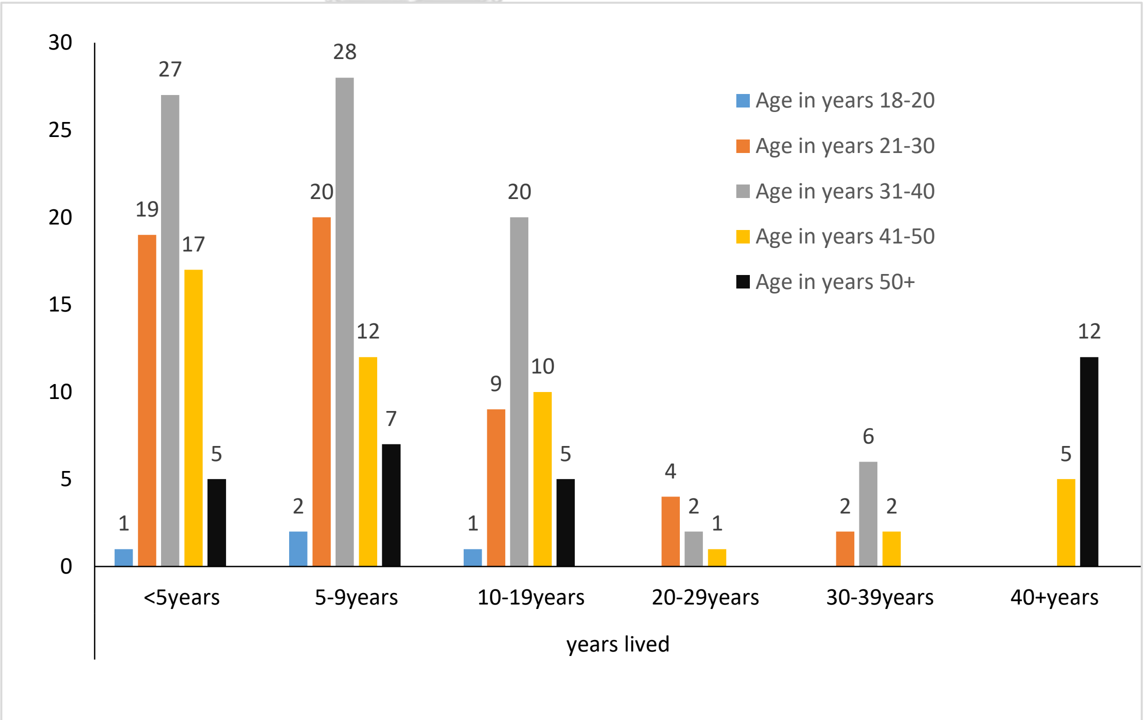

Figure 16 Exposure duration among different age categories

By gender, mean weight of the participants was slightly higher among the male 66.89±11.99 as compared to 59.33±11.47 of the female. The weight of the participants ranges from 41.4 to 96.1 for male and 34.8 to 103.5 for female. The following values will be used for risk assessment.

Table 12Exposure factors and their values

Variable	Unit	Category	Value	source
C_{air}: concentration of HM in dust	*mg/kg*	-		Current study
Inh_{rate}: inhalation rate	*m3/day*	Male	22.8	US EPA, 2011
		Female	21.1	US EPA, 2011
EF: Exposure frequency	*days/year*	-	350	US EPA
ED: Exposure duration	*year*	Non-cancer	14	Current study
		Cancer (Male)	68.8	PHCB, 2017
		Cancer (Female)	71.7	PHCB, 2017
AT: Averaging time	*days*	-	EDx365	
BW: body weight	(Kg)	Male	66.89	NCD STEPs survey, 2019
		Female	59.33	
PEF: Particle emission factor	(m3/Kg		1.32×109	US EPA

4.6 Non-cancer risk characterization

To evaluate the non-cancer risk of exposure to the heavy metals through inhalation, the average daily dose (ADD) was calculated using the concentration of each heavy metal from the study, standard inhalation rate for male and female, exposure frequency and exposure duration, body weight, and averaging time collected through questionnaire. The ADD was calculated using equation 1. The ADD was calculated separately for male and female as they have different standard inhalation rates.

Table 13Average daily dose and Hazard quotients of each heavy metal

		Mean	Standard Deviation	median	Min	Max
Arsenic	ADD	1.14X10-10	3.13X10-11	1.1X10-10	5.98X10-11	2.2X10-10
	HQ	3.66X10-07	1X10-07	3.6X10-07	1.90X10-07	7.2X10-07
Chromium	ADD	2.67X10-09	7.3X10-10	2.6X10-09	1.40X10-09	5.2X10-09
	HQ	1.212x10-3	3.3x10-4	1.17x10-3	6.40x10-4	2.36x10-3
cadmium	ADD	1.29x10-13	6.76x10-14	1.25x10-13	6.76x10-12	2.51x10-13
	HQ	2.67x10-6	7.33x10-7	2.58x10-6	1.14x10-0	5.20x10-6
Mercury	ADD	7.98X10-14	2.2X10-14	7.7X10-14	4.20X10-14	1.6X10-13
	HQ	9.27X10-10	2.6X10-10	9X10-10	4.90X10-10	1.8X10-09
Lead	ADD	7.64X10-12	2.1X10-12	7.4X10-12	4.01X10-12	1.5X10-11
	HQ	2.17X10-09	6X10-10	2.1X10-09	1.1X10-09	4.2X10-09
HI		1.22x10-03	3.34x10-04	1.18x10-03	6.38x10-04	2.37x10-03

The overall mean ADD for the heavy metals were $1.14x10^{-10} \pm 3.13x10^{-11}$, $2.67x10^{-09} \pm 7.3x10^{-10}$, $1.29x10^{-13} \pm 6.76x10^{-14}$, $7.98x10^{-14} \pm 2.2x10^{-14}$ and $7.64x10^{-12} \pm 2.1x10^{-12}$ for As, Cr, Cd, Hg and Pb respectively.

Similarly, the hazard quotient (calculated using equation 2) for As, Cr, Cd, Hg and Pb was $3.66x10^{-07}$±$1x10^{-07}$, $1.212x10^{-3}$±$3.3x10^{-4}$, $2.67x10^{-06}$±$7.3x10^{-07}$, $9.27x10^{-10}$±$2.6x10^{-10}$, $2.17x10^{-09}$±$6x10^{-10}$. The mean HQ for As, Cr, Cd, Hg and Pb for female was $4.48x10^{-7}$, 1.47x10-3, $3.16x10^{-6}$, $1.10x10^{-9}$ and $2.57x10^{-9}$ respectively. Similarly, the HQ for male was $2.95x10^{-7}$, $4.42x10^{-4}$, $2.08x10^{-6}$, 7.24x10-^{10} and $1.69x10^{-9}$ for As, Cr, Cd, Hg and Pb respectively.

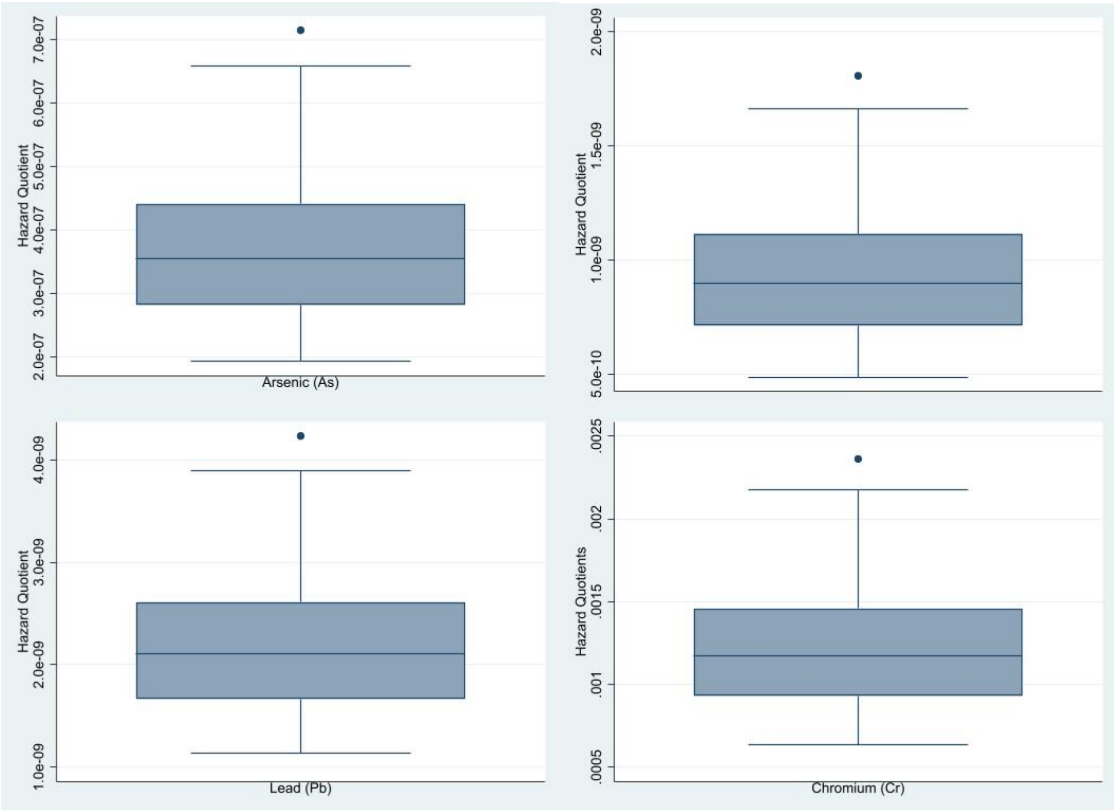

Figure 17 Hazard quotient of heavy metals

4.7 Total non-cancer risk or Hazard Index

The hazard index of the heavy metals or the non-carcinogenic risk of exposure to As, Cd, Cr, Hg and Pb through inhalation in the study area was $1.22x10^{-03}$±$3.34x10^{-04}$, which is lower than the standard hazard index of 1. The non-cancer risk or the mean HI were $9.4 \times 10^{-4} \pm 1.72 \times 10^{-4}$ and $1.3 \times 10^{-3} \pm 2.6 \times 10^{-4}$ for male and female respectively.

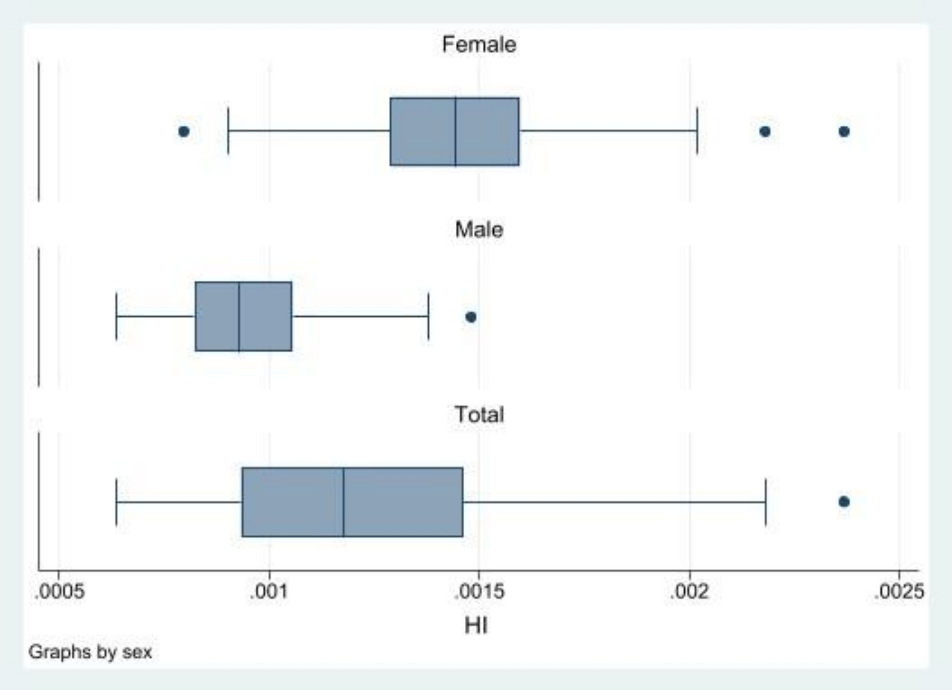

Figure 18 Non-carcinogenic risks of heavy metals by gender

4.8 Cancer risk characterization

For the calculation of the carcinogenic risk, chronic daily intake (CDI) was calculated by using equation 3. The life span of the Bhutanese population (for male and female) was obtained from the population and housing census of Bhutan, 2017. The average life span of Bhutanese population was 68.8 and 71.7 respectively for male and female. The heavy metal concentration, standard inhalation rate (IhR), exposure frequency (EF), exposure duration (ED), body weight (BW), and averaging time (AT) of participants collected from survey for the study was used for calculating the average daily dose (ADD) for cancer risk. For the cancer risk assessment, only As, Cr, Cd and Pb were used. Hg is categorized by US EPA's Integrated Risk Information System

(IRIS) as D (Not classifiable as to human carcinogenicity) and thus excluded for the cancer risk assessment.

Table 12 shows the lifetime cancer risk of each heavy metal. The mean cancer risk of As, Cr, Cd and Pb was 1.64x10^{-09}±4.50x10-10, 4.59x10^{-09}±1.26x10^{-09}, 6.88x10^{-10}±1.89x10^{-10}, 4.59x10^{-12}±1.26 x10^{-12} respectively. The maximum cancer risk of each of these heavy metals were 3.19x10^{-09}, 8.94x10^{-09}, 1.34x10^{-9}, and 8.94x10^{-12} for As, Cr, Cd and Pb which was below the USEPA safety limit of 1 x 10^{-6}.

The cancer risk due to As, Cr, Cd and Pb were 2.20x10-9, 1.33x10-7, 9.61x10-13 and 3.80x10-12 for female, while cancer risk for male were 1.33x10-9, 8.72x10-8, 6.32x10-13, and 2.50x10-13 for As, Cr, Cd and Pb respectively among male.

Table 14 Lifetime average daily dose and cancer risk of exposure to heavy metals

		Mean	Standard Deviation	Median	Min	max
Arsenic	ADD	1.09x10-10	3.00x10-11	1.10x10-10	5.73x10-11	2.13x10-10
	CR	1.64 x10-09	4.50 x10-10	1.59 x10-09	8.60 x10-10	3.19 x10-09
Chromium	ADD	2.56x10-09	7.03x10-10	2.58x10-09	1.34x10-09	4.98x10-09
	CR	4.59x10-09	1.26x10-09	4.45x10-09	2.41x10-09	8.94x10-09
Cadmium	ADD	1.24x10-13	3.54x10-14	1.25x10-13	6.76x10-14	2.51x10-13
	CR	6.88 x10-10	1.89 x10-10	6.67 x10-10	3.61 x10-10	1.34 x10-09
Lead	ADD	7.64x10-12	2.10x10-12	7.40x10-12	4.01x10-12	1.49x10-11
	CR	4.59 x10-12	1.26 x10-12	4.45 x10-12	2.41 x10-12	8.94 x10-12
TCR		6.92x10-09	1.90x10-09	6.70x10-09	3.63x10-09	1.35x10-08

4.9 Total cancer risk

The total cancer risk is the sum of the cancer risk of each heavy metal. The mean total cancer risk in the study area due to exposure to As, Cr, Cd and Pb was 6.92x10-

$^{9}\pm1.90x10^{-9}$. The median risk was $6.70x10^{-9}$ with maximum cancer risk of $1.35x10^{-8}$. Therefore, the overall total cancer risk was below the USEPA safety limit of $1x10^{-6}$.

By gender, total cancer risk for female was $1.35x10^{-7}\pm2.47x10^{-8}$ and slightly higher than male ($8.85x10^{-8}\pm1.61x10^{-8}$). The maximum cancer risk due to exposure to As, Cr, Cd and Pb were $2.22x10^{-7}$ and $1.39x10^{-7}$ for female and male respectively.

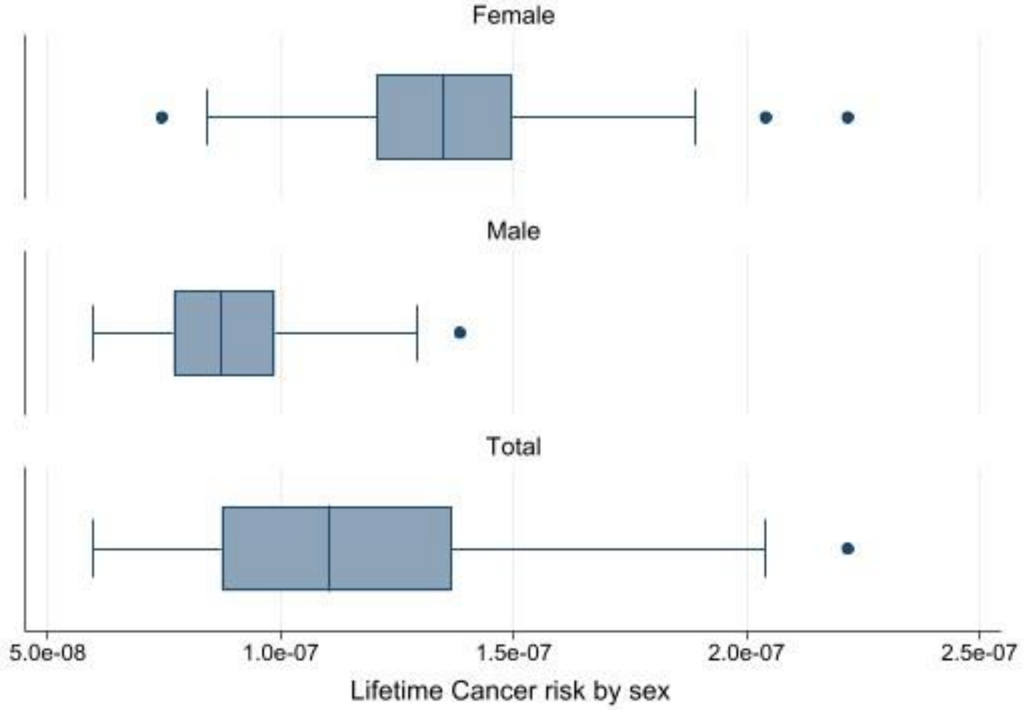

Figure 19 Total cancer risk of exposure to heavy metals

5 CHAPTER V Discussion

5.1 Socio-demographic characteristics of the Participants

Majority of the participants were female (55.36%) and 74.68% of the participants at least attended one form of formal schooling. According to the Population and housing census of Bhutan, the proportion of male population was higher than the female (52.3 and 47.7 percent respectively) (NSB, 2018). The difference could be due to exclusion of the labors and temporary workers (mostly men) in the study. The PHCB 2017 found that the literacy rate among male was 78.1% and 63.9% among female with overall literacy rate of 66.6% (National Statistics Bureau, 2017). The mean age of the participant was 37±9.86; median:35 (percentiles:29-44) and was slightly higher for male. The median age of the Bhutanese population was 26.9 years in 2017 (NSB, 2018). The difference in mean age could be due to exclusion of below 18 years old in the current study.

5.2 Behavioral Characteristics of the study participants

The proportion of smokers, smokeless tobacco user and alcohol users was higher among male as compared to female. The overall prevalence of alcohol consumption of 54.5% among the participants. As per the national STEPS survey 2019, the prevalence of smoking among adults (16-65 years) was 9.8% and males were 3 times more likely to smoke than females (Ministry of Health, 2019). The survey also found that the prevalence of alcohol consumption in the country was 43%. However, the prevalence of alcohol consumption was higher among men at national level (Ministry of Health, 2019).

The use of face mask is also practiced by almost 50% (n:118) of the study participants and was higher among female participants (53.49) as compared to male (47.12%).

This is comparatively higher as compared to other studies from Bhutan. *Tashi et.al* (2022) found that only 22.1% of the study participants (students) were found to use face masks even during the covid-19 period.

5.3 Adverse health symptoms among the study participants

All the participants reported at least one symptom in the past 12 months. A slightly higher number of participants had shortness of breath (55.36%) and headache (54.08%). Headache is the most common symptom of acute poisoning of heavy metals found in many of the related studies. It's also one of the common symptoms for all the heavy metals. Exposure to heavy metals causes headache, allergic dermatitis, nausea, loss of appetite, respiratory diseases, and muscular pain (Okechukwu Ohiagu et al., 2022). The annual health bulletin records from the four health facilities in the area (Kamichu, Taksha, Bjemithangkha and Habesa Primary Health Centers) recorded an increase in cases of Hypertension, arthritis, skin infections, Kidney and genital disorders, and nervous disorders in the study area since 2015 (HMIS, 2016, 2019).

Table 15Cases of health conditions recorded by Kamichu, Taksha, Bjemithangkha and Habesa Primary Health Centers, Wangduephodrang district during 2015 – 2018 (HMIS, 2016, 2019).

	2015	2016	2017	2018
Hypertension	63	42	80	487
Arthritis & Arthrosis	54	256	316	292
Skin Infections	501	866	877	1 468
Kidney, UT/Genital Disorders	148	117	107	182
Nervous including Peripheral Disorders	595	602	461	292

5.4 Concentration of the heavy metals in road-side dusts

The mean concentration of the heavy metals was in order of Cd<Hg<As<Pb<Cr. The mean concentration of the As in the area was 0.65±1.16 mg/kg with median concentration lower than (0.0403mg/kg). The mean concentration of the Cr was 15.71±5.58mg/kg with median concentration of 14.1mg/kg (12.1-18). The concentration of Hg was 0.00047±0.00067mg/kg. However, the concentration was lower than the LOD in many of the areas. The mean concentration of Pb was 5.61±5.90 with median concentration of 4.27mg/kg. The concentration of Cd was lower than the LOD (0.000759) in all the samples. Similar study in China found an average of Cd (0.64)>Cr (69.33)>Pb (201.82) (Du et al., 2013). A study in Nigeria found that the mean concentration of Cd was lower than other heavy metals with average concentration of Pb (25.0–66mg/kg), Cd (1.54–2.58mg/kg), and Cr (1.13–2.79mg/kg) (Mafuyai et al., 2015). While the concentration of heavy metals was lower than many of the studies, the magnitude and the order remain comparable (Aguilera et al., 2022; Al-Swadi et al., 2022; Han et al., 2017; Sultan et al., 2022; Zgłobicki & Telecka, 2021). While all these heavy metals were also found in the fish species of the current study area, the amount differs significantly. The study found 0.122, 0.005, 0.253 and 0.051 mg/kg of As, Cd, Cr and Pb in the muscle of *S. richardsonii*. The concentration of Chromium was 62 times higher in dust than fish (Tashi et al., 2022).

The maximum concentration of Cr in the current study was 27.76mg/kg and was found near hydropower dam I. There is also a statistically significant difference in the Cr concentration between the samples closer to Dam I and II and the concentration of the Cr decreased as we move further from the dam. In contrast to many of the similar studies around the world, the mean concentration of all the heavy metals included in the study were below the maximum allowable limit.

Table 16 Comparison of the Concentrations of Heavy Metals with the Concentrations from other countries

Country	Location	Cr	Pb	Cd	As	Hg	ref
Current study	Roadside dust near hydropower dams	15.71	5.61	>0.000759	0.65	0.00047	
Baotou city,China	Parks and Squares of an Industrial City	142.2	35.5	0.3	6.5	51.3	(Han et al., 2017)
Suleja, Nigeria	Road deposited sediments	19.79	31.42	17.86			(Yisa et al., 2012)
Dhaka, Bangladesh	Megacity	40.78	35.34	0.15	1.56		(Sultan et al., 2022)
Delhi, India	Street road dust)	148.8	120.7	2.65			(Suryawanshi et al., 2016)
Lublin City, Poland	Urban street dust	108.5	62	6.3			(Zgłobicki & Telecka, 2021)
Plateau Stat, Nigeria	Urban dust	1.13-2.78	25-66	1.54-2.58			(Waida et al., 2022)
Shenyang City, China	Surface dust	40.17	41.02	0.37	6.54	0.05	(H. Wang et al., 2021)
Olt River, Romania	Surface sediments	25.19	39.44	0.49	240.14	0.19	(Iordache et al., 2022)
Thessaloniki, Greece	Road dust from Urban	135.9	429	5			(Bourliva et al., 2012)
France	Outdoor playground	25-52	27-254	0.65-1	8-26		(Bourliva et al., 2012)
Distribution in Earth's crust (Shale)		90	20	0.3	13	0.4	(Turekian et al., 1961)

5.5 Exposure assessment

According to National STEPS survey 2019, the average body weight of the Bhutanese population was 61.9±11.76. The average body weight of male and female was 61.19±11.71 and 59.82±11.31 respectively (Ministry of Health, 2019). Similarly, in the current study, the mean weight of the participants was slightly higher among the male (66.89±11.99) as compared to female (59.33±11.47). The weight of the participants ranges from 41.4 to 96.1 for male and 34.8 to 103.5 for female.

The mean exposure frequency was 365 days per year as most of them are employed in the current area or permanently live in the study area. The mean years lived in the area was 14.49±16.94 years with minimum of 1 year and maximum of 60 years. However, the median years spent in the area was 8 years (4-12 years). The hydropower dam construction began in 2008 and therefore the median years lived in the area were equivalent to the project years.

5.6 Non-cancer risk characterization

The overall mean ADD for the heavy metals was in order of Cr>As>Pb>Cd>Hg. The highest mean ADD was found for Cr ($2.67x10^{-9}$±$7.3x10^{-10}$. Further, the hazard quotient for As, Cr, Cd, Hg and Pb was $3.66x10^{-07}$±$1x10^{-07}$, $1.21x10^{-3}$±$3.3x10^{-4}$, $2.67x10^{-06}$±$7.33x10^{-07}$, $9.27x10^{-10}$±$2.6x10^{-10}$, $2.17x10^{-09}$±$6x10^{-10}$. A study from Riyadh and Mahad AD 'Dahab (urban and sub urban) areas found that the HQ of the heavy metals was <1 in all samples from sub-urban areas (Al-Swadi et al., 2022). Similarly, the HQ of Cd and Pb from Bangladesh was $3.94x10^{-11}$ and $1.5x10^{-2}$ respectively (Ahmed et al., 2020). The findings from Bosnia and Herzegovina found that the inhalation unit risk of Pb, Cd, Hg were $8.67x10^{-6}$, $1.15x10^{-7}$ and $4.37x10^{-07}$ for adult men and $1.15x10^{-2}$, $1.15x10^{-7}$. $4.3x10^{-7}$ for adult female respectively (Husejnović et al., 2021). A similar study in Poland also found that the HQ of the heavy metals (Pb, Cr and Cd) was 1.7×10^{-2}, 1.3×10^{-2} and 1.3×10^{-2} in 2018 (Zgłobicki et al., 2018). However, many of the studies conducted in the road-side dusts were much higher than the current study area (Sultan et al., 2022; Tomczyk, Gałka, et al., 2022; Yisa et al., 2012).

The cumulative non-cancer risk or the mean hazard index (HI) of the exposure to the heavy metals through inhalation was $1.22x10^{-3}$±$3.34x10^{-4}$. The mean HI values was less than one for all heavy metals.

5.7 Cancer risk characterization

As per the US EPA, cancer risk of below $1x10^{-6}$ has negligible risk and above $1x10^{-6}$ has moderate detrimental effect on human health. The mean cancer risk of As, Cr, Cd and Pb was $1.64x10^{-09}$±$4.50x10^{-10}$, $4.59x10^{-09}$±$1.26x10^{-09}$, $6.88x10^{-10}$±$1.89x10^{-10}$, 4.59 $x10^{-12}$±1.26 $x10^{-12}$ respectively.

The cancer risk of all the heavy metals in the study were < $1x10^{-6}$. Similarly, the total cancer risk due to exposure to As, Cr, Cd and Pb was $6.92x10^{-9}$±$1.90x10^{-09}$.

A study from Bangladesh assessed the carcinogenic risk of exposure to heavy metal laden dust and found that highest risk was found through inhalation of Cr ($4.89x10^{-8}$) (Sultan et al., 2022). The risk was in chronological order of Cr>Pb>As>Cd. S.Yang *et.al* assessed the health risk of exposure to Cr, Ni, Cu, Zn, Pb and Cd. The study found that the total cancer risks of $2.1x10^{-7}$ (X. Yang et al.,2022).

6 Chapter VI Conclusion and Recommendation

In this study, the non-carcinogenic risk, and the carcinogenic risk of exposure to heavy metals (As, Cr, Cd, Hg and Pb) were assessed on the road-side dust samples from hydropower dam construction areas in Bhutan. The exposure factors were collected through a questionnaire. The assessment was carried out using established methods of human health risk assessment by US EPA and other guidelines.

6.1 Socio-demographic characteristics of the Participants

The mean age of the participant was 37±9.86; median:35 (29-44) and ranges from 20-60. The median age of the Bhutanese population was 26.9 years in 2017 and therefore, the age category of the participants in the current study was comparable to the national mean age of the population. While the PHCB 2017 found that the proportion of male population was higher than the female (52.3 and 47.7 percent respectively), in the current study, most of the participants were female. The major occupation of the participants was also private or employees of the dam construction other than daily wage laborer. The literacy rate of the participants was also equivalent to the national literacy rate (male: 78.1%; Female: 63.9%). Therefore, the socio-demographic characteristics of the current study were comparable to the national population.

6.2 Behavioral Characteristics of the study participants

The proportion of smokers, smokeless tobacco users and alcohol consumption was also higher among male participants. The overall prevalence of alcohol consumption of 54.5% among the participants. The prevalence of smoking among Bhutanese adults (16-65 years) was 9.8%. The prevalence of alcohol consumption in the country was

43% and higher among men at national level. The use of face mask is also practiced by almost 50% of the study participants and was higher among female participants. This is comparatively higher as compared to other studies from Bhutan.

6.3 Adverse health symptoms among the study participants

It's evident that all the participants have at least experienced one of the symptoms in the past 12 months. More than half of them had at least 4-5 symptoms. The most common symptoms were shortness of breath and headache.

6.4 Concentration of the heavy metals in road-side dusts

The mean concentration of the heavy metals was in order of Cd<Hg<As<Pb<Cr. The concentration of all the heavy metals was below the maximum allowable concentration. Moreover, the Cd and Hg concentration was below the LOD and thus signifies very low levels of pollution due to these heavy metals in the area.

The maximum concentration of Cr in the current study was found near hydropower dam I. There is also a statistically significant difference in the Cr concentration between the samples closer to Dam I and II and significant reduction in the Cr concentration as we move further from the dam. Therefore, the chromium could possibly be released in the environment due to hydropower construction works. There was no significant difference in distance and the concentration of As, Hg, Pb and Cd.

6.5 Exposure assessment

The mean weight of the male was 66.89±11.99 and 59.33±11.47 for female. The weight of the participants ranges from 41.4 to 96.1 for male and 34.8 to 103.5 for female. The participants mostly live in the area throughout the year. Most of these residents settled in the area during the onset of the dam construction works and therefore have lived in the area for an average of 14.49 years.

6.6 Non-cancer risk characterization

The overall mean ADD for the heavy metals was in order of Cr>As>Pb>Cd>Hg with median hazard quotient of less than 1 for all the heavy metals. The median cumulative non-cancer risk or the mean hazard index (HI) of the exposure to the heavy metals through inhalation was <1 for all heavy metals. Thus, this study did not find significant non-cancer risk due to exposure to As, Cr, Cd, Pb and Hg through inhalation.

6.7 Cancer risk characterization

The median cancer risk of As, Cr, Cd and Pb was less than $1x10^{-6}$. Similarly, the total lifetime cancer risk due to exposure to As, Cr, Cd and Pb through inhalation was also less than $1x10^{-6}$. As per the US EPA, cancer risk of below $1x10^{-6}$ has negligible risk and above $1x10^{-6}$ has moderate detrimental effect on human health. Thus, this study did not find significant cancer risk due to exposure to As, Cr, Cd, and Pb through inhalation.

6.8 Recommendation

This study provides baseline information regarding the heavy metal concentration and cancer and non-cancer risk related due to exposure to this heavy metal laden dust through inhalation. Therefore, the following recommendations are deemed necessary.

6.8.1 Individual level

Traces of heavy metals were found in the dust samples although no apparent risks were identified. However, this study was limited to five selected heavy metals. It's important for the residents (Individuals) to use face masks to prevent risk of exposure to heavy metals. Moreover, use of face mask is an effective mitigation mechanism to prevent airborne infectious disease transmission and reduce exposure to other aerosols and particulate matters (PM), which is a common pollutant in heavy construction areas. Use of face mask can also reduce exposure to secondhand smoke, which is considered as toxic as smoking. In addition, we recommend individuals to quit smoking and alcohol consumption, which further aggravates the risk of non-cancer and cancer risk, apart from exposure to dust and heavy metals.

6.8.2 Community level

There should be methods to suppress the dust in the community such as sprinkling water. This will also reduce the risk of exposure to dust through other routes (ingestion and dermal contact). Further, to prevent the release of heavy metals in the environment from the earth moving activities and other anthropogenic activities, and to prevent distribution of transportation of heavy metals from the construction area to communities, proper disposal of excavated materials and preventive measures should be implemented.

6.8.3 Government level/ Policy Instruments:

Since higher heavy metal concentrations were observed near the construction area and its association with the distance from the construction areas, policies and strategies need to be developed to prevent people from settling near such areas. Further, periodical monitoring of the heavy metal concentration needs to be conducted in the area. It's also necessary to constantly monitor the health status of the people in the community as long-term exposure to the heavy metals could result in chronic diseases.

6.8.4 Future research

A thorough study on the concentration of heavy metals (all essential and non-essential metals), considering all exposure routes (dermal, inhalation and ingestion) needs to be conducted in such areas to understand the level of risk. Further, it's important to assess the heavy metal contamination in the soil and agricultural fields and assess the risk through other environmental media.

6.9 Limitations of the study

a. This study was a cross-sectional study. Thus, it doesn't consider the seasonal variations in the concentration of the heavy metals, transport mechanisms and distribution.
b. This study only focused on 5 heavy metals (As, Cr, Hg, Pb and Cd). Therefore, the risk presented in this study was limited to the selected heavy metals and doesn't account for other heavy metals in the area.
c. Furthermore, the study only considered inhalation as a route of exposure.

REFERENCES

Abdel-Rahman, G. N. (2022). Heavy metals, definition, sources of food contamination, incidence, impacts and remediation A literature review with recent updates. *Egyptian Journal of Chemistry*, *65*(1), 419–437. https://doi.org/10.21608/EJCHEM.2021.80825.4004

Al-Swadi, H. A., Usman, A. R. A., Al-Farraj, A. S., Al-Wabel, M. I., Ahmad, M., & Al-Faraj, A. (2022). Sources, toxicity potential, and human health risk assessment of heavy metals-laden soil and dust of urban and suburban areas as affected by industrial and mining activities. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-022-12345-8

Armah, F. A., Quansah, R., & Luginaah, I. (2014). A Systematic Review of Heavy Metals of Anthropogenic Origin in Environmental Media and Biota in the Context of Gold Mining in Ghana. *International Scholarly Research Notices*, *2014*, 1–37. https://doi.org/10.1155/2014/252148

Asian Development Bank. (2010). *Independent Evaluation Department Evaluation Study Bhutan: Energy Sector*.

ATSDR. (2007). Arsenic. Relevance To Public Health. In *Toxicologial profile for arsenic* (pp. 15–40). Agency for Toxic Substances and Disease Registry, Division of Toxicology and Environment medicine/Applied Toxicology Brance. https://books.google.co.th/books?id=bNEbUuvh1d4C&pg=PA15&lpg=PA15&dq=Arsenic+is+widely+distributed+in+the+Earth%27s+crust,+which+contains+~3.4+ppm+arsenic.+In+nature,+arsenic+is+mostly+found+in+minerals+and+only+to+a+small+extent+in+its+elemental+form.+Ar

ATSDR. (2020). *Guidance for Inhalation Exposures*. 5–12. chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.atsdr.cdc.gov/pha-guidance/resources/ATSDR-EDG-Inhalation-508.pdf

ATSDR. (2022). *Toxicological Profile for Mercury. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Services. April.*

Bai, J., Cui, B., Xu, X., Ding, Q., & Gao, H. (2009). Heavy metal contamination in riverine soils upstream and downstream of a hydroelectric dam on the lancang river, China. *Environmental Engineering Science*, *26*(5), 941–946. https://doi.org/10.1089/ees.2008.0136

Bhattacharya, P., Ahlfors, A.-S., & Bjerhag, H. (2019). *Arsenic and other heavy metals in hydropower plants An assessment of occupational risk hazards at Fortum's underground hydropower plants in Sweden Supervisor/ Examiner Supervisors at Fortum*.

Bing, H., Liu, Y., Huang, J., Tian, X., Zhu, H., & Wu, Y. (2022). Dam construction attenuates trace metal contamination in water through increased sedimentation in the Three Gorges Reservoir. *Water Research*, *217*(March), 118419. https://doi.org/10.1016/j.watres.2022.118419

Bing, H., Wu, Y., Zhou, J., Sun, H., Wang, X., & Zhu, H. (2019). Spatial variation of heavy metal contamination in the riparian sediments after two-year flow regulation in the Three Gorges Reservoir, China. *Science of the Total Environment*, *649*, 1004–1016. https://doi.org/10.1016/j.scitotenv.2018.08.401

Bourliva, Kantiranis, N., Papadopoulou, L., Christoforidis, C., & Kollias, P. (2012). Heavy metals in road dusts from the centre of the city of Thessaloniki, Greece: A

Mineralogical and Chemical Assessment. *Protection and Restoration of the Environment XI*, *July*.

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, *6*(9), e04691. https://doi.org/10.1016/j.heliyon.2020.e04691

CDC. (2009). *Mercury*. https://www.cdc.gov/biomonitoring/pdf/Mercury_FactSheet.pdf

CDC. (2022). *Blood lead levels in children top 8 ways to protect children from lead exposure*. www.cdc.gov/nceh/lead

Ceballos, D. M., Dong, Z., Peters, J. L., Herrick, R. F., Gupta, P., & Spengler, J. D. (2022). Metals dust in workers' homes and potential for take home in the Greater Boston area: Pilot study. *Environmental Research*, *209*(November 2021), 112893. https://doi.org/10.1016/j.envres.2022.112893

Chen, S., Fath, B. D., & Chen, B. (2010). Ecological risk assessment of hydropower dam construction based on ecological network analysis. *Procedia Environmental Sciences*, *2*, 725–728. https://doi.org/10.1016/j.proenv.2010.10.083

Cheng, Z., Chen, L. J., Li, H. H., Lin, J. Q., Yang, Z. B., Yang, Y. X., Xu, X. X., Xian, J. R., Shao, J. R., & Zhu, X. M. (2018). Characteristics and health risk assessment of heavy metals exposure via household dust from urban area in Chengdu, China. *Science of the Total Environment*, *619–620*, 621–629. https://doi.org/10.1016/j.scitotenv.2017.11.144

Denny, M., Baskaran, M., Burdick, S., Tummala, C., & Dittrich, T. (2022).

Investigation of pollutant metals in road dust in a post-industrial city: Case study from Detroit, Michigan. *Frontiers in Environmental Science*, *10*(September), 1–16. https://doi.org/10.3389/fenvs.2022.974237

Du, Y., Gao, B., Zhou, H., Ju, X., Hao, H., & Yin, S. (2013). Health Risk Assessment of Heavy Metals in Road Dusts in Urban Parks of Beijing, China. *Procedia Environmental Sciences*, *18*, 299–309. https://doi.org/10.1016/j.proenv.2013.04.039

Dytłow, S., & Górka-Kostrubiec, B. (2021). Concentration of heavy metals in street dust: an implication of using different geochemical background data in estimating the level of heavy metal pollution. *Environmental Geochemistry and Health*, *43*(1), 521–535. https://doi.org/10.1007/s10653-020-00726-9

EPA, U. S. (1995). *Guidance for risk characterization*. *l*, 15.

European Investment Bank. (2019). *Environmental, Climate and Social Guidelines on Hydropower Development*. https://www.eib.org/attachments/eib_guidelines_on_hydropower_development_en.pdf

Genchi, G., Sinicropi, M. S., Lauria, G., Carocci, A., & Catalano, A. (2020). The effects of cadmium toxicity. *International Journal of Environmental Research and Public Health*, *17*(11), 1–24. https://doi.org/10.3390/ijerph17113782

Goguitchaichvili, A., & Bautista, F. (2023). *Pollution Levels and Potential Health Risks of Potentially Toxic Elements in Indoor and Outdoor Dust during the COVID-19 Era in G ó mez Palacios City , Mexico*.

Han, X., Lu, X., Qinggeletu, & Wu, Y. (2017). Health risks and contamination levels of heavy metals in dusts from parks and squares of an industrial city in semi-arid area of China. *International Journal of Environmental Research and Public Health*, *14*(8), 1–12. https://doi.org/10.3390/ijerph14080886

IARC. (2012a). *Arsenic, metals, fibres, and dusts* (Vol. 100c, pp. 41–85). International Agency for Research on Cancer, World Health organization. https://www.iarc.fr/

IARC. (2012b). IARC monographs on the evaluation of carcinogenic risks to humans: Cadmium and cadmium compounds. *IARC Monographs*, *1993*, 121–145. https://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-8.pdf

Iordache, A. M., Nechita, C., Zgavarogea, R., Voica, C., Varlam, M., & Ionete, R. E. (2022). Accumulation and ecotoxicological risk assessment of heavy metals in surface sediments of the Olt River, Romania. *Scientific Reports*, *12*(1), 1–11. https://doi.org/10.1038/s41598-022-04865-0

Jonasson, M. E., & Afshari, R. (2018). Historical documentation of lead toxicity prior to the 20th century in English literature. *Human and Experimental Toxicology*, *37*(8), 775–788. https://doi.org/10.1177/0960327117737146

Jyothi, N. R. (2020). Heavy Metal Sources and Their Effects on Human Health. In M. Nazal & H. Zhao (Eds.), *Heavy Metals - Their Environmental Impacts and Mitigation*. IntechOpen. https://doi.org/http://dx.doi.org/10.5772/57353

Kubier, A., Wilkin, R. T., & Pichler, T. (2019). Cadmium in soils and groundwater: A review. *Applied Geochemistry*, *108*, 1–42.

https://doi.org/10.1016/j.apgeochem.2019.104388

Mafuyai, G. M., Kamoh, N. M., Kangpe, N. S., Ayuba, S. M., & Eneji, I. S. (2015). Heavy Metals Contamination in Roadside Dust along Major Traffic Roads in Jos Metropolitan Area , Nigeria. *Journal of Environment and Earth Sciences*, *5*(5), 48–58. http://iiste.org/Journals/index.php/JEES/article/download/20656/21224

Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. Bin, Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., & Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University - Science, 34*(3), 101865. https://doi.org/10.1016/j.jksus.2022.101865

Nazarpour, A., Ghanavati, N., & Watts, M. J. (2018). Spatial distribution and human health risk assessment of mercury in street dust resulting from various land-use in Ahvaz, Iran. *Environmental Geochemistry and Health*, *40*(2), 693–704. https://doi.org/10.1007/s10653-017-0016-5

NOISH. (1994). *The National Institute for Occupational Safety and Health*. Lead Compounds (as Pb). https://doi.org/10.1111/j.1600-0536.1977.tb03696.x

NSB. (2018). 2017 Population Housing and Census, National Report. In *National Statistics Bureau of Bhutan*. Royal Government of Bhutan. www.nsb.gov.bt

OEHHA. (2017). *Lead and lead compounds, inorganic*. California Office of Environmental Health Hazar Assessment. https://oehha.ca.gov/

OSHA. (2006). Health Effects of Hexavalent Chromium. In *OSHA Fact Sheet*. https://www.osha.gov/OshDoc/data_General_Facts/hexavalent_chromium.pdf

Rai, R. (2021). Contamination of surface water resources by wastewater in Bhutan : A review. *Journal of the Bhutan Ecological Society*, *4*, 9–24.

Rai, R., Sharma, S., Gurung, D. B., & Sitaula, B. K. (2019). Heavy metal contamination in sediments from vehicle washing: a case study of Olarong Chhu Stream and Paa Chhu River, Bhutan. *International Journal of Environmental Studies*, *76*(1), 66–83. https://doi.org/10.1080/00207233.2018.1525851

Road Safety and transport Authority. (2022). Annual Report 2021-2022. In *Road Safety and transport Authority*. https://www.rsta.gov.bt/rstaweb/load.html?id=96&field_cons=MENU

Road Safety and Transport Authority. (2009). *ANNUAL REPORT : FINANCIAL YEAR 2008-2009*. https://www.rsta.gov.bt/rstaweb/load.html?id=96&field_cons=MENU

Saad, A. A. A., El-Sikaily, A., & Kassem, H. (2016). Essential, non-essential metals and human health. *Pollution Status, Environmental Protection, and Renewable Energy Production in Marine Systems*, *November*, 87–135.

Sharma, G. P., Sapkota, R. P., Mool, E., Gurung, T., & Maskey Byanju, R. (2021). Status of Air Pollution over the Last Three Decades in Thimphu City, Bhutan. *Journal of Institute of Science and Technology*, *26*(1), 119–127. https://doi.org/10.3126/jist.v26i1.37839

Singh, N., & Li, J. H. (2014). Environmental impacts of lead ore mining and smelting. In *Advanced Materials Research* (Vol. 878, Issue October). https://doi.org/10.4028/www.scientific.net/AMR.878.338

Slobodian, M. R., Petahtegoose, J. D., Wallis, A. L., Levesque, D. C., & Merritt, T. J. S. (2021). The effects of essential and non-essential metal toxicity in the drosophila melanogaster insect model: A review. *Toxics*, *9*(10). https://doi.org/10.3390/toxics9100269

Streets, D. G., Horowitz, H. M., Lu, Z., Levin, L., Thackray, C. P., & Sunderland, E. M. (2019). Global and regional trends in mercury emissions and concentrations, 2010–2015. *Atmospheric Environment*, *201*(December 2018), 417–427. https://doi.org/10.1016/j.atmosenv.2018.12.031

Sultan, M. B., Choudhury, T. R., Alam, M. N. E., Doza, M. B., & Rahmana, M. M. (2022). Soil, dust, and leaf-based novel multi-sample approach for urban heavy metal contamination appraisals in a megacity, Dhaka, Bangladesh. *Environmental Advances*, *7*. https://doi.org/10.1016/j.envadv.2021.100154

Suryawanshi, P. V., Rajaram, B. S., Bhanarkar, A. D., & Chalapati Rao, C. V. (2016). Determining heavy metal contamination of road dust in Delhi, India. *Atmosfera*, *29*(3), 221–234. https://doi.org/10.20937/ATM.2016.29.03.04

Tan, S. Y., Praveena, S. M., Abidin, E. Z., & Cheema, M. S. (2016). A review of heavy metals in indoor dust and its human health-risk implications. *Reviews on Environmental Health*, *31*(4), 447–456. https://doi.org/10.1515/reveh-2016-0026

Tashi, S., Gurung, D. B., Dorji, U., & Wangchuk, K. (2022). Trace elements in fish species: Schizothorax richardsonii, Salmo trutta and Neolissochilus hexagonolepis in relation to sizes and tissues of Punatsang Chhu. *Environmental Chemistry and Ecotoxicology*, *4*, 78–88. https://doi.org/10.1016/j.enceco.2022.01.001

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. In *EXS* (Vol. 101, pp. 133–164). https://doi.org/10.1007/978-3-7643-8340-4_6

The World Bank. (2019). *Bhutan Development Update: Recent trends in poverty and shared prosperity: progress and challenges Macroeconomics, Trade, and Investment Global Practice*.

The World Bank. (2020). *Bhutan Development Update: Recent trends in poverty and shared prosperity: progress and challenges Macroeconomics, Trade, and Investment Global Practice*. http://documents.worldbank.org/curated/en/746771583997797516/Bhutan-Development-Update

Tokmechi, Z. (2011). Dust pollution and its effects in construction sites. *Advances in Environmental Biology*, *5*(9), 2652–2657.

Tomczyk, P., Gałka, B., Wiatkowski, M., Buta, B., & Gruss, Ł. (2021). Analysis of spatial distribution of sediment pollutants accumulated in the vicinity of a small hydropower plant. *Energies*, *14*(18). https://doi.org/10.3390/en14185935

Tomczyk, P., Gałka, B., Wiatkowski, M., Wdowczyk, A., & Gruss, Ł. (2022). Toxicity studies on sediments near hydropower plants on the Ślęza and Bystrzyca rivers, Poland, to establish their potential for use for soil enrichment. *Land Degradation and Development*, *33*(5), 756–770. https://doi.org/10.1002/ldr.4210

Tomczyk, P., Wiatkowski, M., Gałka, B., & Gruss, Ł. (2022). Assessing the Impact of a Hydropower Plant on Changes in the Properties of the Sediment of the Bystrzyca River in Poland. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.795922

Turekian, K. K., Haven, N., Hans, K., & Universitat, W. M. Der. (1961). KARL K. TUREKIAN Dept. Geology, Yale University, New Haven, Conn. KARL HANS WEDEPOHL Mineralogische-Institut der Universitat, Gottingen, Germany Distribution of the Elements in Some Major Units of the Earth's Crust. *America*, *February*, 175–192.

U.S. EPA, (United States Environmental Protection Agency). (1998). Toxicological review of Trivalent Chromium. *Toxicological Review Of Trivalent Chromium (CAS No. 16065-83-1) - In Support of Summary Information on the Integrated Risk Information System (IRIS)*, *16065*, 51pp. https://iris.epa.gov/static/pdfs/0028tr.pdf

US EPA. (1988). *Mercury Elementary*. Mercury, Elemental CASRN 7439-97-6 | DTXSID1024172. https://doi.org/10.7551/mitpress/11856.003.0002

US EPA. (1992). Guidelines for Exposure Assessment, EPA/600/Z-92/001. *Risk Assessment Forum, Washington, DC, 1992.*, *57*(May), 22888–22938. http://ngha.med.sa/English/MedicalCities/AlMadinah/MedicalDepartments/Pages/default.aspx

US EPA. (1997). *Lead Exposure Associated With Renovation and Remodeling Activities : Worker Characterization and Blood-Lead Study* (Issue May). https://nepis.epa.gov/Exe/ZyNET.exe/2000JK7U.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=

&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=

US EPA. (1998). Chromium (VI) (CASRN 18540-29-9). *IRIS, US EPA ORD NCEA Integrated Risk Information System*, *Vi*, 1–33. http://www.epa.gov/iris/subst/0144.htm

USEPA - U.S. (2005). *Environmental Protection Agency. Guidelines for carcinogen risk assessment*. *March*. http://www.epa.gov/sites/production/files/2013-09/documents/cancer_guidelines_final_3-25-05.pdf

Waida, J., Rilwan, U., Ismail, W. O., Yusuf, I. M., & Sunday, B. I. (2022). Pollution Load Index of Heavy Metals Resulting from Mining Activities in Plateau State, Nigeria. *Journal of Radiation and Nuclear Applications*, *7*(3), 75–81. https://doi.org/10.18576/jrna/070310

Wang, B., Wang, Z., Wei, Y., Wang, F., & Duan, X. (2015). Inhalation Rates. *Highlights of the Chinese Exposure Factors Handbook*, *September*, 15–21. https://doi.org/10.1016/b978-0-12-803125-4.00012-2

Wang, H., Zhao, Y., Walker, T. R., Wang, Y., Luo, Q., Wu, H., & Wang, X. (2021). Distribution characteristics, chemical speciation and human health risk assessment of metals in surface dust in Shenyang City, China. *Applied Geochemistry*, *131*(March), 105031. https://doi.org/10.1016/j.apgeochem.2021.105031

Wangchuk, T., Kinga, Wangdi, U., Tshering, U., & Wangdi, K. (2023). Hand Hygiene, Face Mask Use, and Associated Factors during the COVID-19

Pandemic among the Students of Mongar Higher Secondary School, Bhutan: A Cross-Sectional Study. *International Journal of Environmental Research and Public Health*, *20*(2), 1058. https://doi.org/10.3390/ijerph20021058

WHO. (1998). Environmental health criteria 61: Chromium. In *Environmental Health Criteria*. https://apps.who.int/iris/bitstream/handle/10665/40419/9241542616-eng.pdf?sequence=1&isAllowed=y

WHO. (2021). Mercury and human health. In *World Health Organization*.

Witkowska, D., Słowik, J., & Chilicka, K. (2021). Review heavy metals and human health: Possible exposure pathways and the competition for protein binding sites. *Molecules*, *26*(19). https://doi.org/10.3390/molecules26196060

Wong, C. S. C., Li, X., & Thornton, I. (2006). Urban Environmental Geochemistry of Trace Metals: A Review. *Environmental Pollution*, *142*(1), 1–16. https://www.sciencedirect.com/science/article/abs/pii/S0269749105004811?via%3Dihub

World Health Organization (WHO). (2022). Lead Poisoning. In *World health Organization*. https://doi.org/10.1136/bmj.4.5834.230-a

WSP Environment & Energy. (2010). Framework for the Management of Contaminated Land Contents Page Protocol for Site Risk Assessment Application of Site Specific Quantitative Risk Assessment. In *Energy* (Issue March). www.wspenvironmental.co.za

Yang, S., Liu, J., Bi, X., Ning, Y., Qiao, S., Yu, Q., & Zhang, J. (2020). Risks related to heavy metal pollution in urban construction dust fall of fast-developing

Chinese cities. *Ecotoxicology and Environmental Safety*, *197*(January), 110628. https://doi.org/10.1016/j.ecoenv.2020.110628

Yang, X., Eziz, M., Hayrat, A., Ma, X., Yan, W., Qian, K., Li, J., Liu, Y., & Wang, Y. (2022). Heavy Metal Pollution and Risk Assessment of Surface Dust in the Arid NW China. *International Journal of Environmental Research and Public Health*, *19*(20). https://doi.org/10.3390/ijerph192013296

Yangka, D., Rauland, V., & Newman, P. (2019). Carbon neutral policy in action: the case of Bhutan. *Climate Policy*, *19*(6), 672–687. https://doi.org/10.1080/14693062.2018.1551187

Yisa, J., O. Jacob, J., & C. Onoyima, C. (2012). Assessment of Toxic Levels of Some Heavy Metals in Road Deposited Sediments in Suleja, Nigeria. *American Journal of Chemistry*, *2*(2), 34–37. https://doi.org/10.5923/j.chemistry.20120202.08

Zgłobicki, W., & Telecka, M. (2021). Heavy metals in urban street dust: Health risk assessment (Lublin city, e Poland). *Applied Sciences (Switzerland)*, *11*(9). https://doi.org/10.3390/app11094092

Zgłobicki, W., Telecka, M., Skupiński, S., Pasierbińska, A., & Kozieł, M. (2018). Assessment of heavy metal contamination levels of street dust in the city of Lublin, E Poland. *Environmental Earth Sciences*, *77*(23), 1–11. https://doi.org/10.1007/s12665-018-7969-2

Zhang, H., Cui, B., Xiao, R., & Zhao, H. (2010). Heavy metals in water, soils and plants in riparian wetlands in the Pearl River Estuary, South China. *Procedia*

Environmental Sciences, *2*, 1344–1354. https://doi.org/10.1016/j.proenv.2010.10.145

Zhang, L., Gao, Y., Gao, Y., Wu, S., Zhang, S., Smith, K. R., Yao, X., Yao, X., Gao, H., & Gao, H. (2020). Global impact of atmospheric arsenic on health risk: 2005 to 2015. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(25), 13975–13982. https://doi.org/10.1073/pnas.2002580117

APPENDICES

Appendix 1: Ethical Clearance from Research Ethics Board of Health, Bhutan

དཔལ་ལྡན་འབྲུག་གཞུང་།
གསོ་བ་ལྷན་ཁག།
གསོ་བའི་ ཞིབ་འཚོལ་ ཀུན་སྤྱོད་རྣམ་གཞག་ བཀོད་ཚོགས།
ཐིམ་ཕུག།

ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF HEALTH
RESEARCH ETHICS BOARD OF HEALTH
THIMPHU : BHUTAN
P.O. BOX : 726

Ref. No. REBH/Approval/2023/013 — 20th May, 2023

REBH APPROVAL LETTER (valid through 20th April, 2024)

PI: Mr.Kinley Dorjee **Institute:** College of Public Health sciences, Chulalongkorn University	**Study Title**: Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan

Co-Investigator(s): 1. Dr. Pokkate

Proponent of the study: Individual

Mode of Review:

Initial Review : ✔ *Expedited Review*

Date of continuing review: 20th April, 2024

Note: Please submit continuing review report along with application form AF/01/015/05 at least seven days before the date of continuing review. If the study is completed, then please submit final report of the study.

List of documents(s) approved:

Protocol : V12
Informed Consent Form (ICF) : ICF V2
Tools (Questionnaire/forms/guides/etc) : V1 (questionnaire)

Conditions for Approval:

1. *This approval is granted for the scientific and ethical soundness of the study. The PI shall be responsible to seek all other clearances/approvals required by law/policy including permission from the study sites before conducting the study.*
2. *Report serious adverse events to REBH within 10 working days after the incident and unexpected events should be included in the continuing review report or the final report.*
3. *No biological material shall be used for other research purpose beyond which is specified in this protocol.*
4. *Any new research study with stored biological material from this study will need a new approval from the REBH before study begins.*
5. *Any changes to the proposal or to the attachments (informed consent and research tools such as forms) shall be approved by REBH before implementation.*
6. *Final report of the study shall be submitted to REBH at the end of the study for review and protocol file closure.*

(Dr. Tandin Zangpo)
Vice Chairperson, REBH

Appendix 2 Administrative clearance from Ministry of Health

དཔལ་ལྡན་འབྲུག་གཞུང་། གསོ་བ་ལྷན་ཁག།

ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF HEALTH
THIMPHU BHUTAN
P.O BOX: 726

MoH/PPD/ADM.CL/9/2023/033 **26/4/2023**

Mr. Kinley Dorjee
College of Public Health sciences
Chulalongkorn University

Subject: **Administrative Clearance**

Dear Kinley,

The Ministry of Health is pleased to issue Administrative Clearance for the study titled " Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan" after reviewing its purpose, objectives, and intended outcome(s). However, the following conditions needs to be fulfilled for the clearance to be valid:

1. Obtain technical and ethical clearance from Research Ethics Board of Health (REBH) or KGUMSB Institutional Review Board (*if the sites of the study are confined to KGUMSB or its affiliated teaching hospitals)* prior to the conduct of study and ensure strict adherence to its requirements, terms, and conditions.
2. Abide by national policies and laws applicable to the study;
3. Seek approval from work site(s) prior to the conduct of study;
4. Ensure no interference with routine delivery of health services at the study site(s);
5. Concurrence for movement of health saff (if any) for the purpose of the study from Department of Medical Services and study sites from the concerned authorities at least one month prior to the conduct of the study;
6. Respond within 10 working days to queries (if any) from the Ministry of health with regard to the implementation of the study: and
7. Share a signed copy of the report with Planning and Policy Division, Ministry of Health

Thanking you.

Yours sincerely,

(Tashi Penjor)
Chief Planning Officer

PABX: + 975-2-322602, 322351, 328091, 328092, 328093 Minister: 323973 Fax: 323113 Secretary 326627
Fax: 324649 HRD: Tel/Fax- 323953 Extension 333

Appendix 3

	members	Household income	sex	Age (in years)	Weight (Kg)	Education	Occupation	place of work	marital status	smoking	alcohol	from dust when going outdoor	how often did you have these symptoms	following near the house:	How long have you lived in this area	do you spend working indoors	Spend outdoors
Expert 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Expert 2	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1
Expert 3	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
IOC	1	1	1	1	0.67	1	1	1	0.67	0.67	1	1	1	1	1	1	1

Appendix4: Questionnaire

Screening Question

When do you settle in this place?	1 More than 6 months	2 Less than 6 Months
Age	1 <20 or >60	2 20-60
Nationality	1 non-Bhutanese	2 Bhutanese
Is the respondent suffering from any chronic illness (COPD, TB, Cancer, cognitive disability	1 Yes	2 No

If 1 for any of the above questions, go to the next respondent.

Socio-demographic information

Gender	☐ Male ☐ Female
Age (in years)	
Household Weight (Kg)	
Height (cm)	
Education (Highest qualification)	☐ Lower than primary school ☐ Primary school ☐ secondary school ☐ High school ☐ Certificate or diploma ☐ Bachelor’s degree ☐ Higher than Bachelor ☐ ECCD or day care
Occupation (usual occupation)	Home maker Office worker Farmer Daily wage worker Shopkeeper/hotelier Student Others (please specify……………………….)
Place of work	1 Hydropower dam construction 2 others
Marital status	Never married Living together Married Divorced Separated Widow
Smoking	Never Yes ex-smoker
alcohol	Yes No
Do you use face mask to protect from dust when going outdoor:	☐ Never ☐ Sometimes ☐ Often ☐ Always

Health information

Do you have any of the following condition	Yes	No
None	Yes	No
Stroke	Yes	No
Anemia	Yes	No

Approximate Distance from the Dam		
Approximate distance from road		

Cancer	Yes	No	
Diabetes	Yes	No	
Hypertension	Yes	No	
Heart disease (CVD)	Yes	No	
Kidney disease	Yes	No	
COPD / Asthma	Yes	No	
Tuberculosis	Yes	No	
Depression	Yes	No	
Infertility	Yes	No	
abortions	Yes	No	
Other (specify on left)	Yes	No	
Are you currently taking any medicines for the above listed health Conditions? (if yes, list)	Yes	No	
Do any of your children have Developmental or health problems? (If yes, please list below)	Yes	No	
In past 6 months, how often did you have these symptoms	never	occasional	Often
Headaches			
Anxiety, Nervousness, Irritable, Severe shyness			
Forgetfulness, Lack of concentration			
Burning or watery eyes			
Increase in salivation/(drooling)			
Nausea/Vomiting/Diarrhea			
Difficult breathing/Shortness of breath			
Cough			
Clumsiness or Tremors			
Muscles aches			
Increased Tiredness			
Skin rash			

Residential Information

Type of House		
Is there any of the following near the house:		
Mucking sites (disposal of excavated earth materials)	Yes	No
Dumping of waste materials from the construction area (excluding excavated soil and rocks)	Yes	No
Any ongoing construction works	Yes	No
Auto repair workshops and carwash	Yes	No

Exposure factors

How long have you lived in this area:	
Work indoor or outdoor?	
How long do you work in this area (Daily, in hrs.)	
How many hours do you spend working indoors (at home)	………………hrs/day
Spend outdoors	………………hrs/day

Appendix 5 Informed consent form

Research Participant Information Sheet and Consent Form

Title of research project: Human Health Risk Assessment of Heavy Metals in Roadside Dust Near Hydropower Dams Construction Areas in Wangduephodrang District of Bhutan

Principal researcher's name: Kinley Dorjee **Position** Student: Master of Public Health
Office address: College of Public Health Sciences, Chulalongkorn University
Home address: Thimphu, Bhutan
Cell phone 17450682 **E-mail:** kuenleg32@gmail.com

Sponsor/Funding organization (if any)..TICA/TIPP

Introduction

You are being invited to take part in a research project. Before you decide to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and do not hesitate to ask if anything is unclear or if you would like more information.

1. **Purpose of the research.**

Due to hydropower dam construction in the area, dust pollution has increased in the area. Therefore, the aim of the study is to study the health risks due to exposure to dust in the area.

2. **Processes of interview**

The enumerators are qualified and trained interviewers, and they have prior knowledge of conducting such interviews. The interviewer will visit all the selected households and explain the purpose of the study, process of selection and administration of the questionnaire-based interview to each member in the household. You may ask or interrupt in the middle, if you have any questions or doubts about the study. However, if you wish to read the information sheet, we will also share the information sheet with you for you to read and understand the details of the interview. The individuals who are present today will be interviewed today. However, we will return to interview the other individuals who are not present today.

3. **Details of participant**.

This study will recruit 250 participants. Firstly, the households in the study area were line listed. From the line list, 63 households were selected randomly. Your household falls on the randomly selected list. All the members will be included in the study if they consent to participate in the study. However, they will be asked a few questions to see if they fit the inclusion criteria of the study. All individuals aged 18-65 and have lived in the area for more than 6 months will be included in the study. However, Non-Bhutanese individuals (including the labors) working in the area, those who moved out and resettled recently in the area (less than 6 months) and who has severe illness (clinically diagnosed) such as cancer, TB, cognitive disability, and COPD will be excluded from the study.

4. **Procedure upon participants:**

After you agree to participate in the study, the interviewers will ask a few questions to assess if you fulfil the inclusion criteria and exclusion criteria in the study. If you are found eligible for participation in the study, the interviewers will start the interview using the questionnaire.

The questionnaire has four parts. The part 1 contains questions on socio-demographic information such as your age, sex, weight, education, occupation, workplace, smoking status, alcohol consumption and use of facemask. Part II has questions on whether you have experienced any symptoms related to heavy metal poisoning in the last year. They will read out each symptom. The 3rd part of the questionnaire will ask about residential information such as type of house, presence of any activity that elevates the heavy metal content. The list will be read to you. In the last section, it contains questions to assess the exposure to heavy metal such as duration of your stay in the area, work hours and nature of work. The entire interview will not take more than 25 minutes.

5. risk/harm.

Since this is social research and no interventions are involved, there are no risks to the participants.

6. **Benefit**

While there is monetary benefit or direct benefit to the participants. However, this study will help identify and assess the level of heavy metals in the dust and cancer and non-cancer risk of exposure to dust in the area. This will help develop better interventions by the relevant stakeholders through informed decision making. Further, the policy makers can also design and develop appropriate measures to prevent such risk in future projects.

Your participation is very important for such decision making. We would like to thank you for your support and time. However, there is no monetary compensation associated with your participation in the study.

8. **Confidentiality**

The information that we collect from this research project will be kept confidential. No personal identifiers will be included in the report apart from generic analysis and situation information. Information about you that will be collected during the research will be accessible only to the researchers. However, if there is a need to share the data, only anonymized data after removing your identifiable information will be shared. The data will be stored on an encrypted disk.

The data collected from this study will be securely stored for 5 years (standard of REBH) and destroyed after that.

9. **Right to Refuse or Withdraw**

While you were selected for this study, your participation in this research is entirely voluntary. It is your choice whether to participate or not. Whether you choose to participate or not, all the services you receive will continue and nothing will change. If you choose not to participate in this research project, it will not have any consequences later. You are free to withdraw participation and revoke consent without giving any reasons during the interview if you wish to discontinue.

12. if you have any questions or would like to obtain more information, the researcher can be always reached. The researcher can be contacted at 17450682 or kuenleg32@gmail.com.

13. However, if researcher does not perform upon participants as indicated in the participant information sheet and consent form, participants can report the incident to the Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University (RECCU) Jamjuree 1 Bldg., 254 Phyathai Rd., Patumwan district, Bangkok 10330, Thailand, Tel./Fax. 0-2218-3202, 0-2218-3049 E-mail: eccu@chula.ac.th” or Research Ethics Board of Health, Bhutan at REBH secretariat at Mongal S. Gurung, secretary, msgurung@health.gov.bt

I have been explained by researcher and understand all the details provided. And I voluntarily signed my name to enroll in this project and receive a copy of this document.

Sign..	Sign..
(..)	(..)
Principal investigator	Research participant
Date......../............./....................	Date......../............./....................

Sign..
(..)
Witness
Date......../............./....................

VITA

NAME	Kinley Dorjee
DATE OF BIRTH	25 January 1992
PLACE OF BIRTH	Bhutan
INSTITUTIONS ATTENDED	College of Natural Resources, Punakha Bhutan Royal Insititute of Management, Bhutan
HOME ADDRESS	Thimphu, Bhutan