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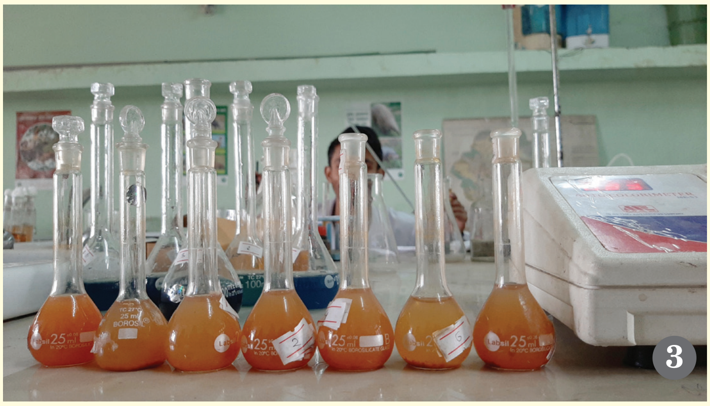

Government of Nepal
Ministry of Forests and Environment
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Editorial Board

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Photo 1 Brick kiln emitting smoke over agricultural land, contributing to air pollution and soil degradation. © Melina Koirala

Photo 2 Lower-Barun Glacial Lake (area: 2.0 sq.km.), a proglacial lake located in the south of Mt. Makalu (8485 m asl.), is one of the rapidly expanding glacial lakes in Nepal himalaya. © Sudeep Thakuri

Photo 3 Determination of iron concentraion in the water samples using Phenonthroline Method © Hira Bahadur Karki

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Editorial

It is our pleasure to present the current issue of the *Journal of Environment Sciences*, Volume XI, 2025. This edition includes fourteen articles encompassing a wide range of thematic areas and cross-cutting issues in the field of environment. The journal compiles valuable knowledge and research outcomes contributed by professionals from government agencies, non-governmental and international organizations, and academic institutions, making it a comprehensive annual publication.

The *Journal of Environment Sciences* continues to serve as a platform for sharing environmental information and strengthening collaboration among researchers, academicians, professionals, and policymakers. Our aim is to foster meaningful coordination and dialogue that can contribute to evidence-based decision-making and policy formulation. We believe that the findings, insights, and recommendations contained in this volume will support efforts toward sustainable development and effective environmental governance.

We would like to clarify that the views expressed in the articles are solely those of the authors and do not necessarily reflect the official position of the Department of Environment.

We extend our sincere appreciation to all contributing authors, researchers, reviewers, and the dedicated personnel of the Department of Environment for their support in making this publication possible. With your continued cooperation and feedback, we are committed to maintaining the regularity and quality of this journal in the years to come.

Thank you.

Editorial Board

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Concentration and Pollution Characteristics of Heavy Metals in Rooftop Dust Deposition on Buildings of Varying Heights in Kathmandu Metropolitan Area

Bhushan Shakya[1], Supriya Kandel[2], Bindra Devi Shakya[3], Deepak Chhetry Karki[4], Pawan Raj Shakya[5*]
[1]Department of Chemistry, Amrit Campus, Tribhuvan University, Kathmandu, Nepal
[2]Department of Environmental Science, Padmakanya Multiple Campus, Tribhuvan University, Kathmandu, Nepal
[3]Department of Mathematics and Statistics, Padmakanya Multiple Campus, Tribhuvan University, Kathmandu, Nepal
[4]Department of Environmental Science, Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal
[5]Department of Chemistry, Padmakanya Multiple Campus, Tribhuvan University, Kathmandu, Nepal
[*]Correspondence: pawansh2003@yahoo.com

Abstract

Heavy metals (HMs) in dust act as potential indicators of air pollution and pose significant risks to both human health and the environment. This study investigates the concentrations and pollution characteristics of six heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in rooftop dust collected from three types of concrete buildings of varying heights: low-rise buildings (LRB), medium-rise buildings (MRB), and high-rise buildings (HRB) in the Kathmandu metropolitan area. A total of 36 dust samples were collected from the buildings during the dry season (March–April 2024) and analyzed for HMs content using flame atomic absorption spectrophotometry (FAAS). Pollution assessment was conducted using four indices: contamination factor (C_f), degree of contamination (C_{deg}), pollution load index (*PLI*), and geo-accumulation index (I_{geo}). Results indicated that the mean HM concentrations were highest in dust from low-rise buildings, with all measured values exceeding background levels. The overall abundance of metals (mg/kg) in rooftop dust followed the order: Zn (372.0) > Cu (85.9) > Cr (69.3) > Ni (65.8) > Pb (56.2) > Cd (0.65). Pollution assessment using the contamination factor (C_f) and degree of contamination (C_{deg}) revealed values ranging from 0.42 to 5.06 and 7.83 to 15.72, respectively, indicating low to considerable and considerable levels of contamination across all building types, with zinc (Zn) identified as the predominant pollutant. Pollution load index (*PLI*) values greater than 1.0 in this study confirmed that rooftop dust was polluted in all cases. Meanwhile, geo-accumulation index (I_{geo}) values ranging from 0.11 to 1.03 indicated a contamination level from unpolluted to moderately polluted. These findings suggest that vehicular emissions, industrial activities, construction and demolition, and other anthropogenic sources are the primary contributors to rooftop dust contamination in the metropolitan area.

Keywords*: Ecological risk assessment, Heavy metal pollution, Kathmandu metropolitan city, Pollution index, Rooftop dust*

Introduction

Heavy metals are naturally occurring elements with high atomic weights and densities exceeding 5 g/cm³. Common environmental heavy metals include lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu), and nickel (Ni), which are toxic even at low concentrations. Many originate from anthropogenic activities such as industrial emissions, vehicular exhaust, construction, and waste disposal (Charlesworth et al., 2003; Zhang et al., 2016). Due to their non-biodegradable nature and ability to accumulate in the environment and living organisms, heavy metals pose significant threats to human health and ecosystems. They can enter the human body through various pathways, including inhalation, ingestion, and dermal absorption (Napit et al., 2020; Bhandari et al., 2021).

Dust particles, comprising soil, airborne particles, building materials, soot from industrial and vehicle emissions, and heavy metals, significantly contribute to urban pollution (Niroula et al., 2022). These particles can be resuspended into the atmosphere, further dispersing heavy metals and exacerbating pollution levels. Consequently, these metals may pose health risks to urban dwellers, particularly in areas with high levels of anthropogenic activity

(Vegter, 2007). Studies on the chemical composition of roadside dust have shown that it contains potentially toxic metals such as Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Ti, and Zr, along with organic contaminants (Banerjee, 2003). Numerous studies have demonstrated that both soil and dust particles possess a higher capacity to bind and transport heavy metals (Shakya et al., 2019; Niraula et al., 2022). Prolonged exposure to elevated levels of heavy metals can lead to both acute and chronic toxicity, causing damage to the central and peripheral nervous systems, blood composition, lungs, kidneys, and liver, and potentially resulting in death (Georgaki & Charalambous, 2022; Sudharshan Reddy & Sunitha, 2023). Additionally, the neurological, gastrointestinal, hormonal, cardiovascular, and reproductive systems are also directly affected (Ismanto et al., 2022; Jamali et al., 2023). Young children are particularly at risk for heavy metal poisoning, as this stage is critical for optimal brain development and growth (Lin et al., 2020).

Kathmandu is one of the most densely populated cities in Nepal, with an approximate density of 28,418 people per km² according to the 2021 Census of Nepal. It has not developed a substantial transport infrastructure that includes a metro, light rail, or trams, and instead relies predominantly on public transport options like buses, microvans, taxis, private vehicles, and motorbikes. Consequently, these vehicles contribute to heavy road traffic, which is considered the primary cause of air pollution in the city center. The contamination of soil and road dust systems in Kathmandu with heavy metals can be attributed to rapid population growth, industrial development, increasing urbanization, and various other anthropogenic activities (Bhandari et al., 2021; Niraula et al., 2022). Additionally, Kathmandu is experiencing rapid and chaotic demolition and construction activities, often in violation of building regulations and bylaws. According to the "Nepal National Building Code NBC 206: 2024" (NBC, 2024), there are four types of building construction classified by their stories and heights: low-rise or general, medium-rise, high-rise buildings, and skyscrapers. Low-rise or general buildings (1 to 5 stories or below 16 m) are those whose heights are within reach of firefighters' ladders and hose streams. These buildings are typically accessible without elevators, making them the most common type of structure overall in Nepal, including Kathmandu metropolitan city. Medium-rise buildings (6 to 8 stories or 16 to 24 m) have heights that are accessible to fire hose streams. In emergencies, firefighters can use stairways for rescue in these structures. High-rise buildings (9 or more up to 39 stories, ≥ 25 to below 100 m) exceed the reach of standard firefighting equipment on the ground. Rescue operations in emergencies require fire lifts on the upper floors of these buildings. Skyscrapers (40 stories and above, and ≥ 100 m) necessitate new approaches to safety, design, and technology, and have yet to be experimented with in Nepal; therefore, they are not covered by the code. All these construction types in Kathmandu not only obstruct air movement but also cause their upper surfaces to accumulate dust, serving as a significant secondary source of dust. In dusty environments, adults may inhale as much as 100 mg of dust each day (Rout et al., 2012). Local communities in these areas suffer from exposure to heavy metals in dust, resulting in harmful health effects.

In recent decades, there has been growing interest in the potentially toxic heavy metals found in soils and road dust because of their harmful effects on the environment and human health. Niraula et al. (2022) assessed the ecological risks of heavy metals in various land-use urban soils of Kathmandu. Similar studies by Shakya et al. (2019) and Napit et al. (2020) focused on assessing contamination and pollution characteristics associated with heavy metal exposure in street dust within Kathmandu. Bhandari et al. (2021) evaluated the health risks posed by heavy metals in indoor dust in Kathmandu. The study by Pradhananga et al. (2017) concentrated on heavy metal accumulation in dust from indoor ceiling fans in residential areas of the Kathmandu metropolitan city, while Shakya et al. (2017) analyzed heavy metals in fine particle size fractions from roadside dust in the same city. Moreover, the studies conducted by Bourliva et al. (2017), Roy et al. (2019), Castillo-Nava et al. (2020), and Sadeghduost et al. (2020) primarily focused on the ecological risk assessment of heavy metals in road dust across various countries. Similarly, Javid et al. (2021) and Song et al. (2022) assessed the ecological risks of heavy metals in air dust fall particles in Iran and rooftop dust at various building heights in China, respectively. An in-depth analysis of existing literature reveals that only limited research has concentrated on the pollution characteristics of heavy metals in dust deposits on rooftops of different building types worldwide, with Kathmandu being no exception. The Kathmandu metropolitan area has become densely populated, resulting in significant socio-economic and land-use changes. The city contains many vulnerable areas with metal contaminants arising from rampant construction and demolition, traffic emissions, waste disposal, and industrial activities. Consequently, this study aims to quantify the concentrations of six heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in rooftop dust collected from buildings of varying heights in the Kathmandu Metropolitan Area. Additionally, the study evaluates the pollution characteristics of these heavy metals using multiple pollution assessment indices to enhance understanding of their environmental implications. While previous research has primarily focused on ground-level or ambient air pollution (Shakya et al., 2019; Napit et al., 2020; Bhandari et al., 2021; Niraula et al., 2022), this study is unique and presents a novel investigation into the vertical stratification of heavy metal accumulation on rooftops, providing new insights into how buildings of differing heights influence pollutant deposition patterns in densely populated and topographically complex urban areas like Kathmandu. This approach is particularly innovative concerning Kathmandu, a rapidly urbanizing city with limited green infrastructure and poor air quality. The findings are expected to provide baseline information for urban planning and public health strategies by highlighting height-related disparities in pollutant exposure in densely populated urban settings.

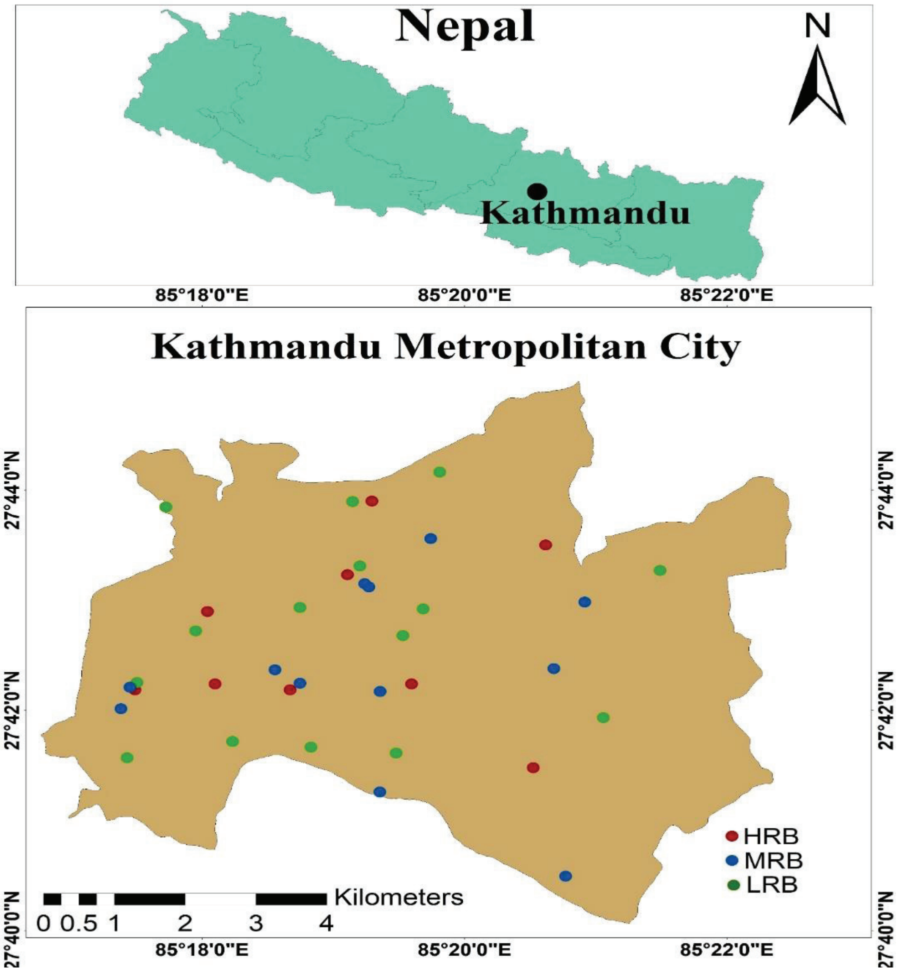

Figure 1: Map of the study area and sampling sites indicating building types across Kathmandu metropolitan.

Materials and Methods

Study area and selection of sampling sites

Kathmandu Metropolitan City (KMC), also known as Kathmandu Municipality (Fig. 1), is the capital and largest city of Nepal. It serves as the political, cultural, and economic center of the country. The city is located in the Kathmandu Valley, a basin-like area in central Nepal, surrounded by the Shivapuri, Phulchoki, and Nagarjun hills. Covering an area of 50.67 sq. km, it is positioned at a latitude of 27.7° N and a longitude of 85.3° E, with an elevation of approximately 1,400 meters above sea level. The city's average annual precipitation is about 1,400 mm, primarily occurring during the monsoon season from June to September.

The city's landscape is diverse, featuring certain flat areas and others that gently slope to the south. According to the 2021 Census of Nepal, the population of KMC is approximately 1.4 million, with an estimated growth rate of about 2.22% per year. The city experiences a moderate climate influenced by its altitude, boasting an average annual temperature of around 16°C. This metropolitan area is divided into 32 wards, each responsible for local administration, public services, and infrastructure development.

For this study, preliminary information was gathered from the office of Kathmandu Metropolitan City (KMC) and relevant government agencies regarding the classifications of building types by law in Nepal. Among the four building categories identified according to the "Nepal National Building Code NBC 206: 2024" (NBC, 2024), only the first three types, *viz.*, low-rise or general, medium-rise, and high-rise buildings located in the metropolitan area, were selected for sampling in this study. To achieve this, a field survey was conducted to identify several potential sampling sites, including the desired building types and areas encompassing commercial, heavy-traffic, and residential zones in the Kathmandu metropolitan city. Regarding the sampling technique, we adopted a purposive sampling approach. Buildings were chosen based on their height category (low-, medium-, and high-rise) from commercial, heavy-traffic, and residential areas across the Kathmandu metropolitan area, as well as rooftop accessibility and safety considerations. This non-probability sampling method allowed us to target locations most relevant to the study's objectives while ensuring representation of different building heights. Only concrete structures from all three building types were selected within each land use category to maintain uniformity in sampling. For sampling purposes, the number of selected low-rise, medium-rise, and high-rise buildings was 15, 12, and 9, respectively. The sample size was considered based on the availability and accessibility of suitable buildings within the study area and land-use types (table 1), taking into account logistical and safety considerations, particularly for high-rise structures. Despite the variation in sample numbers, we ensured sufficient representation across all height categories to allow for reliable comparison and spatial assessment. The location map (Fig. 1) illustrates the sampling points for rooftop dust collection from the three building types across the Kathmandu metropolitan area using GIS mapping methods, while table 1 provides a brief overview of the building types, number of samples, locations, and land use types for sampling.

Table 1: Description of building types and sampling sites across Kathmandu metropolitan city.

Sample code	Building type	Height/ stories (floors)	No. of samples (n)	Location of sampling sites	Land-use type for sampling
LRB	Low-rise or general	<16m / 1 to 5	15	Sinamangal, Maharajganj, Thamel, Naxal, Ranibari, Teku, Bauddha, Balaju, Dallu, Bafal, Tripureshwor, Babarmahal, Kalanki, Lazimpat, Kamalpokhari	Commercial, heavy traffic, and residential areas
MRB	Medium-rise	16 – 24m / 6 to 8	12	Tahachal, Baluwatar, Lazimpat, Indrachowk, Koteshwor, Chabahil, Gonbabu, Kalimati, Putalisadak, Thapathali, Battishputali, Bafal	Commercial, heavy traffic, and residential areas
HRB	High-rise	≥ 25 to below 100m / 9 or more	9	Tahachal, Bafal, Kalikasthan, Sobha bhagawati, Lazimpat, Dhumbarahi, New Baneshwor, Gongabu, Newroad	Commercial, heavy traffic, and residential areas

Sample collection and analytical procedure

During the dry season (March-April 2024), a total of 36 dust samples falling on the rooftops of all three building types were collected. Sample collection from each building type involved sweeping an area of approximately 1 m² with a brush and a plastic dustpan. Two corners and the center of the rooftop area were gently swept and mixed. Care was taken to avoid contamination from rooftop flower vases or kitchen gardens, if present. Dust samples from each structure were collected three times at regular intervals and mixed homogeneously within each category to account for potential variations in elemental concentrations. The dust collected from each building type and sampling site weighed between 250 and 500 g. The sweeping was done carefully, and the dust was collected directly into labeled plastic bags to prevent the resuspension of fine particles during sample collection. Consequently, each dust sample consisted of a composite mixture of three sub-samples collected simultaneously during three successive collections from each structure and sampling site. In the laboratory, the collected dust samples were air-dried at room temperature for two weeks and sifted to remove pebbles, leaves, and other debris. The samples were stored as stock in properly labeled plastic bags with zip locks and kept in a dry location for further processing and analytical purposes.

The concentration of six heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in dust samples was determined using a Perkin Elmer AAnalyst 800 Atomic Absorption Spectrophotometer equipped with an AS-800 autosampler and cooling system, utilizing an air-acetylene flame atomizer. These heavy metals were selected due to their well-documented toxicity, strong association with urban anthropogenic sources (e.g., traffic, industrial emissions), and significance to human health. Furthermore, these metals are frequently used as indicators of environmental pollution in urban studies. A microwave-assisted acid digestion method was employed to extract the total quantities of the analyzed heavy metals from rooftop dust samples (USEPA, 1994). Accordingly, a pre-weighed quantity (1.0 g) of an air-dried dust sample was processed for chemical extraction with 10 mL of concentrated HNO_3 and then heated in a microwave using a CEM, Mars HP 500 microwave extraction system. After complete digestion, the solution was filtered through medium-textured Whatman filter paper, diluted to 25 mL with double-distilled water, and stored in plastic bottles. A similar method was used for all dust sample solutions. All certified standard solutions (1000 ppm) for Cd, Cr, Cu, Ni, Pb, and Zn were obtained from FLUKA AG, Switzerland, for calibration. These solutions were carefully diluted to the required concentrations using double-distilled water. All glass and plastic containers were treated with a diluted (1:1) nitric acid solution for 24 hours and washed with double-distilled water before use. The nitric acid (E. Merck, Germany) was of analytical grade and used without additional purification. The instrumental settings followed the manufacturer's recommendations. The precision and accuracy of the analytical method were verified by analyzing standard reference materials NIST SRM 1648. The recovery percentages for metal concentrations from the reference materials were 98.5 (Cd), 97.8 (Cr), 97.3 (Cu), 99.0 (Ni), 98.5 (Pb), and 98.0 (Zn). To assess the accuracy of the analytical procedure, several samples from the sampling locations were examined three times. The calculated standard deviations for the pretested samples were 3.1, 2.1, 2.5, 2.9, 2.2, and 3.0% for Cd, Cr, Cu, Ni, Pb, and Zn, respectively, which are considered acceptable for the analysis of dust samples. The detection limits for Cd, Cr, Cu, Ni, Pb, and Zn in dust samples using FAAS were 0.5, 2.0, 1.0, 2.0, 0.5, and 2.0 μg^{-1}, respectively.

Pollution characteristics of heavy metals in rooftop dust

Estimation of pollution indicators

In this study, the Contamination Factor (C_f), Degree of Contamination (C_{deg}), Pollution Load Index (PLI), and Geoaccumulation Index (I_{geo}) were determined to evaluate the pollution characteristics of rooftop dust samples in urban areas. The C_f was used to assess the degree of metal contamination and the probable contribution of anthropogenic sources (Yuen et al., 2012).

This factor was first proposed by Håkanson (1980) and was computed using the following equation.

$$Cf = Cn/Bn \quad (1)$$

where C_n represents the measured concentration of the target heavy metal (HM) in dust and B_n denotes the geochemical background concentration of the corresponding heavy metal. Due to insufficient data on the background concentrations of HMs in Nepal's soils, we adopted the background values of HMs from Turekian and Wedepohl (1961). Accordingly, the background concentrations for Cd, Cr, Cu, Ni, Pb, and Zn are 0.3, 90, 45, 68, 20, and 95 mg/kg, respectively.

The C_{deg} represents the sum of contamination factors for all the HMs and indicates the integrated pollution index. This contamination index, derived from the six measured HMs in rooftop dust, was determined as follows (Håkanson, 1980).

$$Cdeg = \sum Cf \quad (2)$$

Hakanson (1980) suggested four C_f and C_{deg} classes to evaluate the heavy metal (HM) contamination levels (table 2).

The PLI aids in quantifying and evaluating pollution levels in a given area, including air, water, or soil. It represents an integrated approach to pollution that simplifies the understanding of pollution intensity. Additionally, the index is particularly useful for identifying areas with higher pollution loads. The index is defined as the geometric mean of the contamination factor (C_f) for the nth metals (Madrid et al., 2002) and was calculated using Eq. (3):

$$PLI = \sqrt[n]{Cf1\ x\ Cf2\ x\ Cf3\ x \dots\dots\dots\dots..Cfn} \quad (3)$$

where C_f is the contamination factor and n is the number of elements. A PLI value >1 indicates polluted soil, whereas <1 indicates no pollution (Tomlinson et al., 1980).

The I_{geo} has recently been utilized as a quantitative measure to assess the extent of heavy metal contamination in airborne dust deposition (Xinming et al., 2022) and soils (Xiong et al., 2017). It reflects the effects of both anthropogenic activity and natural geological processes. The index, first introduced by Muller (1969), was calculated using Eq. (4).

$$Igeo = log2\left[\frac{Cn}{1.5\ Bn}\right] \quad (4)$$

where C_n represents the measured concentration of the target heavy metal, and B_n denotes the geochemical background concentration. The constant 1.5 serves as the background matrix correlation factor, accounting for lithological variability. According to Muller (1969), the I_{geo} values are classified into seven categories of heavy metal pollution levels (table 3).

Table 3: Classification of pollution levels based on geo-accumulation index (I_{geo}) values.

Degree of pollution	I_{geo} value	Classification of heavy metal pollution levels
0	$I_{geo} \leq 0$	Unpolluted
1	$0 < I_{geo} \leq 1$	Unpolluted to moderately polluted
2	$1 < I_{geo} \leq 2$	Moderately polluted
3	$2 < I_{geo} \leq 3$	Moderately to heavily polluted
4	$3 < I_{geo} \leq 4$	Heavily polluted
5	$4 < I_{geo} \leq 5$	Heavily to extremely polluted
6	$I_{geo} \geq 5$	Extremely polluted

Statistical analysis

Data processing and statistical evaluation were performed on an IBM-PC computer using Excel spreadsheets. Descriptive statistics (such as frequency, mean, range, standard deviation, etc.) were conducted following the elemental analysis. A Box and Whisker plot was utilized to summarize the distribution of a dataset of heavy metals in rooftop dust falls. Pearson's correlation coefficient was used to assess the correlation between the metals, along with a significance test (p<0.05).

Table 2: Classifications of contamination levels based on the contamination factor (C_f) and degree of contamination (C_{deg}) values.

Class	C_f value	Level of HM contamination	C_{deg} value	Degree of HM contamination
I	$C_f < 1$	Low	$C_{deg} < 5$	Low
II	$1 \leq C_f < 3$	Moderate	$5 \leq C_{deg} < 10$	Moderate
III	$3 \leq C_f < 6$	Considerable	$10 \leq C_{deg} < 20$	Considerable
IV	$6 \leq C_f$	Very high	$20 \leq C_{deg}$	Very high

Results and Discussion

Heavy metal (HM) concentrations in rooftop dust

Table 4 displays the concentrations of analyzed heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) found in the dust accumulation on the rooftops of three types of buildings.

Results revealed that these buildings exhibited varying concentrations of heavy metals (HMs) in their rooftop dust. The order of HMs in the rooftop dust of low-rise buildings (LRB) was Zn > Cu > Cr > Ni > Pb > Cd. Similarly, medium-rise buildings (MRB) demonstrated HM contents as Zn > Cu > Ni > Cr > Pb > Cd, while high-rise buildings (HRB) displayed them in the order of Zn > Cu > Cr > Pb > Ni > Cd. The concentrations of heavy metals differed slightly across building heights. These variations may be attributed to differences in sources, particle sizes, and the vertical transport dynamics of atmospheric particles. Zn and Cu, which were dominant across all building types, are linked to fine particles and sources such as vehicular emissions, brake and tire wear, and industrial activities, which can be transported vertically. Cr, Ni, and Pb, often associated with coarser particles or ground-based activities (e.g., construction, residual fuel combustion), show more variability in vertical deposition patterns due to gravitational settling and local turbulence. Similar vertical variations in metal composition have been observed in studies of urban particulate matter deposition (Chen et al., 2010; Zhang et al., 2018; Li et al., 2020). The results of this study are consistent with the findings of Song et al. (2022), which similarly noted elevated levels of Zn and the lowest levels of Cd among the analyzed heavy metals in rooftop dust from structures of different heights in China. Castillo-Nava et al. (2020) also reported the lowest level of Cd among the HMs tested in dust from Monterrey, Mexico. In this study, the overall mean concentrations of heavy metals (mg/kg) were ranked as follows: Zn (372.0) > Cu (85.9) > Cr (69.3) > Ni (65.8) > Pb (56.2) > Cd (0.65). Among the HMs examined, only Cr and Ni had overall mean concentrations lower than their background levels (Turekian & Wedepohl, 1961). Moreover, the percent accumulation of the six heavy metals ($\sum_6$HM) in rooftop dust in this study, shown in Fig. 2, was found in the order of LRB (44%) > HRB (29%) > MRB (27%). The HMs in dust falling on the rooftops of building structures could be attributed to several factors, many of which relate to local environmental conditions and human activities (Song et al., 2022). These may include local industrial activities, automobile exhaust, historical contamination, atmospheric

Table 4: Statistical parameters of heavy metal concentration (mg/kg) in dust deposition on the rooftops of different building types.

Heavy metal	Statistical parameters	LRB (n=15)	MRB (n=12)	HRB (n=9)	Overall mean	Background value
Cd	Mean	0.84	0.63	0.47	0.65	
	Range	0.47 – 1.32	0.40 – 0.81	0.30 - 0.75		0.3
	SD	0.27	0.11	0.14		
Cr	Mean	98.1	50.8	60.0	69.3	
	Range	67.8 – 127.8	36.7 – 62.4	39.0 – 79.8		90
	SD	17.7	8.1	13.0		
Cu	Mean	117.5	79.0	61.2	85.9	
	Range	85.0 – 148.3	50.5 – 108.7	40.0 – 81.2		45
	SD	17.1	17.5	13.4		
Ni	Mean	95.0	57.8	44.5	65.8	
	Range	62.5 – 128.0	35.4 – 81.7	30.0 – 60.7		68
	SD	21.0	14.9	10.7		
Pb	Mean	66.8	46.7	55.1	56.2	
	Range	41.0 – 92.5	32.9 – 65.0	39.6 – 72.0		20
	SD	14.8	10.7	10.6		
Zn	Mean	489.6	288.8	337.6	372.0	
	Range	315.7 – 632.7	195.0 – 393.6	234.9 – 481.3		95
	SD	96.2	62.9	84.2		
$\sum_6$HM		867.8	523.7	558.9		

deposition, geological sources, and urban practices. Environmental conditions such as wind patterns, rainfall, and waste disposal practices can exacerbate these issues (Biswas, 2015). In this study, higher concentrations of HMs in the rooftop dust of low-rise buildings might be due to proximity to local sources such as traffic, transport of HMs through varying sizes of windborne particles, or industrial activities (Song et al., 2022).

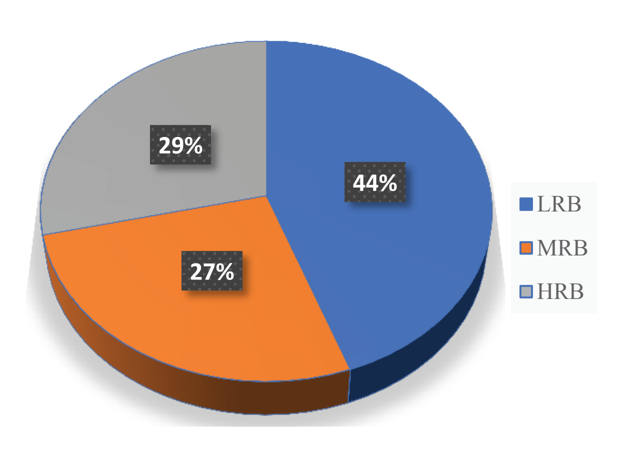

Figure 2: Percent accumulation of $\sum_6$HM in dust deposition on rooftops of different building types in Kathmandu metropolitan city.

The Box and Whisker plots (Fig. 3) for various building types showed differing interquartile ranges, suggesting that building height may influence the distribution of HM concentrations in dust fall on rooftops. The plots highlight key statistical features (median, range, interquartile range, and outliers), aiding in the recognition of trends, variations, and potential risks in the urban environment. This visualization method is particularly useful and advantageous over others when comparing multiple groups, such as metal concentrations across buildings of varying heights, as it allows for clear, compact comparisons of variability and skewness in the data (McGill et al., 1978).

From Table 4, the mean concentration of Cd in dust collected from the rooftops of three building types can be arranged in the order of LRB > MRB > HRB. The LRB recorded the highest concentration of Cd (0.84 mg/kg), while the HRB measured the lowest level at 0.63 mg/kg. Nevertheless, the Cd levels in all the building types exceeded the background level of 0.3 mg/kg. Cadmium is a relatively rare heavy metal that occurs naturally in combination with Zn. Possible sources of Cd in the dust include emissions from vehicles, automobile lubricants, and Zn-reinforced tires (Al-Khashman, 2003). Additionally, wear and tear, as well as the burning of vehicle tires, are reported as human-induced sources of cadmium in the dust (Shakya et al., 2019). Similar to Cd, the Cr content in rooftop dust from LRB was higher than that of MRB and HRB. However, the mean elemental concentration (mg/kg) was found in the order of LRB (98.1) > HRB (60.0) > MRB (50.8). In this case, only the Cr level from the HRB type exceeded the background concentration (90.0 mg/kg). Chromium originates from both geogenic and anthropogenic sources in the environment. Potential sources of Cr contamination in dust include traffic emissions and industrial activities like the chrome plating of vehicle parts and alloys, particularly stainless steel (Johansson et al., 2009; Mollaer et al., 2005). Additionally, Cr is also discharged into the environment through sewage and fertilizers (Ghani & Ghani, 2011).

Similar to the Cd levels, the highest mean concentration of Cu was found in LRB (117.5 mg/kg), followed by MRB (79.0 mg/kg) and HRB (61.2 mg/kg) in that order. The mean concentrations of Cu in rooftop dust across all three building types exceeded the background concentration (45.0 mg/kg). Sources of Cu in dust include sewage sludge, inorganic fertilizer, and atmospheric deposition (Panagos et al., 2018). In addition to Zn and Cd, Cu contamination in soil and dust has been associated with car components, tire abrasion, lubricants, oil product leaks, and emissions from industries and incinerators (Markus & McBratney, 1996). Following the trend of Cu content, Ni also showed its mean concentration in a descending order: LRB > MRB > HRB. LRB had the highest Ni concentration (95.0 mg/kg) in rooftop dust, while the elemental concentrations in MRB and HRB were 57.8 and 44.5 mg/kg, respectively. Only LRB was found to exceed the Ni level above the background level of 68.0 mg/kg. Like chromium, Ni is also a notable component of traffic emissions (Johansson et al., 2009). The corrosion of cars, tire rims, cylinders, and pistons in motor engines is a potential source of Ni contamination in dust (Fergusson & Kim, 1991).

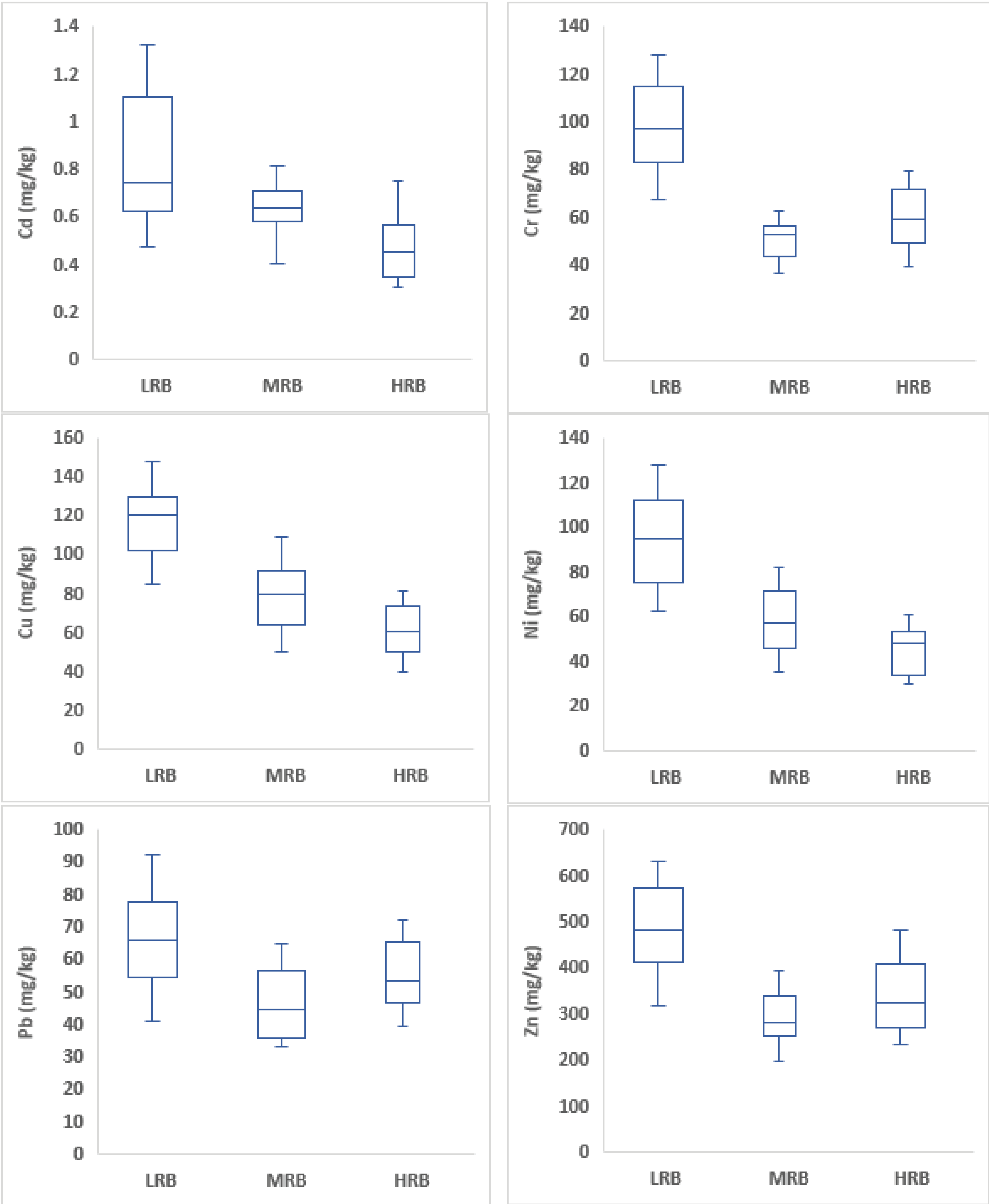

Figure 3: Box and whisker plots of heavy metal concentration showing minimum and maximum values along with median, 25th, and 75th percentile (central box) in rooftop dust of three building types.

The results indicated that the mean concentration of Pb in LRB was measured at 66.8 mg/kg. The MRB and HRB exhibited Pb concentrations of 46.7 and 55.1 mg/kg, respectively. Therefore, the sequence of mean concentrations of Pb can be arranged as LRB > HRB > MRB. It was observed that the mean Pb levels in the rooftop dust of all building types exceeded the background level of Pb (20.0 mg/kg). A significant contributor to Pb in dust comes from the wear of automobile tires, engine components, and leaks from batteries, as well as gasoline that contains Pb (Rout et al., 2013). Additionally, the low solubility of Pb contributes to its prolonged presence in a dusty environment (Yuen et al., 2012). Zinc levels in dust on rooftops across all building types were notably elevated among the HMs examined in this study. The LRB had the highest Zn level (489.6 mg/kg), followed by HRB (337.6 mg/kg) and MRB (288.8 mg/kg) in descending order. The results also revealed that the levels of Zn in the rooftop dust ranged between 315.7 – 632.7 mg/kg, 195.0 – 393.6 mg/kg, and 234.9 – 481.3 mg/kg for LRB, MRB, and HRB, respectively. The mean concentrations of Zn in all three building types surpassed the background concentration of 95.0 mg/kg. The elevated levels of Zn may have resulted from emissions from motor vehicles, the deterioration of brake systems, and galvanized zinc coatings. Faiz et al. (2009) stated that higher road temperatures in summer may cause significant tire wear in vehicles, leading to elevated Zn levels in road dust. Zinc in the form of zinc oxide is retained in the rubber matrix.

Based on table 4, it can be noted that low-rise structures exhibited higher concentrations of all heavy metals (HMs) tested in their rooftop dust compared to medium and high-rise buildings in the Kathmandu metropolitan area. The elevated HM levels in low-rise buildings are primarily due to their proximity to ground-level sources, such as traffic, dust resuspension, and industrial activities, which release coarser particles that settle quickly. In contrast, higher levels in high-rise buildings are often attributed to finer particles (e.g., Zn, Cu) that remain airborne longer and are transported upward by wind and atmospheric turbulence. This vertical distribution pattern has also been reported in other urban environments (Buccolieri et al., 2010; Li et al., 2020). Song et al. (2022) also observed elevated levels of HMs in the rooftop dust of low-rise buildings in China, noting the highest levels of Zn in building structures of varying heights, consistent with the present study. Shakya et al. (2019) showed increased levels of Zn in dust samples from various land use types in Kathmandu. Similarly, elevated levels of Zn in the street dust of Delhi, India, were reported by Roy et al. (2019), in Monterrey, Mexico, by Castillo-Nava et al. (2020), and in Dezful, Iran, by Sadeghdoust et al. (2020). In all cases, Zn was found to be more mobile than other heavy metals due to its smaller ionic size and greater binding affinity for dust particles. However, the extent of their mobility and binding affinities depends on the redox potential and pH of the surrounding dust environment (Hermann & Neumann-Mahlkau, 1985). The findings of this study suggest that the elevated levels of HMs in dust accumulating on rooftops across all types of buildings in the Kathmandu metropolitan region may be attributed to Earth's crust sources (such as road dust, construction dust, and distant dust transmission) as well as emissions from fossil fuel combustion (including vehicle emissions, coal burning, biomass burning, and industrial activities).

Correlation of heavy metals

Pearson correlation coefficients were calculated to establish the relationships among elements in the rooftop dust samples. Understanding these relationships can help identify the source of the elements and their distribution in the environment (Rodriguez et al., 2008). Table 5 illustrates the relationships between various heavy metals in a correlation matrix.

Table 5: Correlation matrix of heavy metals.

	Cd	Cr	Cu	Ni	Pb	Zn
Cd	1.000					
Cr	**0.519***	1.000				
Cu	**0.506***	**0.761***	1.000			
Ni	0.359	**0.832***	**0.765***	1.000		
Pb	0.369	0.438	**0.585***	0.257	1.000	
Zn	0.372	0.306	**0.602***	0.300	**0.634***	1.000

*Correlation is significant at $p<0.05$

It is evident from this matrix that Cr exhibited the strongest positive and significant correlation at $p < 0.05$ with Ni (0.832). The element also positively and significantly correlated with Cu (0.761) and Cd (0.519). This strong positive correlation suggests that these elements share common sources of contamination. Similarly, Cu showed a positive and significant correlation at $p < 0.05$ with Cd (0.506), Ni (0.765), Pb (0.585), and Zn (0.602). Additionally, Pb also had a positive and significant correlation with Zn (0.634) at $p < 0.05$. The sources of these heavy metals likely stem from anthropogenic activities (for Cr, Cd, and Ni metals), such as traffic and the wear and tear of vehicle rims and tires (Varrica et al., 2003). Likewise, the use of leaded gasoline, lubricating oil and grease, waste burning, industrial gases, vehicle emissions, engine part corrosion, and brake emissions may be potential sources of Cu, Pb, and Zn contaminants in dust (Lu et al., 2009; Kong et al., 2012). Moreover, a moderate correlation coefficient among Cd-Pb (0.519), Cd-Cu (0.506), Cu-Pb (0.585), Cu-Zn (0.602), and Zn-Pb (0.634) may imply that these elements share similar sources to some extent or at least one common source (Faiz et. al., 2009). A weak correlation matrix among the other elements suggests various or distinct sources.

Pollution characteristics of heavy metals (HMs)

The pollution characteristics of heavy metals (HMs) in rooftop dust deposition on buildings of varying heights in the Kathmandu metropolitan area were evaluated using both single and integrated pollution indices. The contamination factor (C_f) and geo-accumulation index (I_{geo}) are single pollution indices (Håkanson 1980), while the degree of contamination (C_{deg}) (Müller, 1969) and pollution load index (*PLI*) (Madrid et al., 2002) are integrated pollution indices.

Contamination factor (C_f) and degree of contamination (C_{deg})

The C_f indicates the amount of metal released into dust by human activities compared to that metal's natural or background level. At the same time, C_{deg} measures the total accumulation of metals in dust due to human influences. The C_f and C_{deg} values calculated for each building category, along with the level and degree of HM contamination, are summarized in table 6.

Among the building categories, LRB exhibited comparatively higher C_f values for all analyzed heavy metals (HMs) in rooftop dust, ranked in the decreasing order of Zn > Pb > Cd > Cu > Ni > Cr. The MRB and HRB also demonstrated a similar sequence regarding their C_f values. However, LRB showed various levels of contamination, ranging from moderate ($1 \leq C_f < 3$) to considerable ($3 \leq C_f < 6$) based on the C_f values, while the MRB and HRB categories indicated contamination levels from low ($C_f < 1$) to considerable ($3 \leq C_f < 6$). Thus, LRB presented a moderate level of contamination (1 d" C_f< 3) for Cd, Cr, Cu, and Ni, and a considerable level ($3 \leq C_f < 6$) for Pb and Zn. The MRB and HRB revealed low levels of contamination ($C_f < 1$) for Cr and Ni, moderate levels ($1 \leq C_f < 3$) for Cd, Cu, and Pb, and considerable levels ($3 \leq C_f < 6$) for Zn. Still, every building category showed a considerable level ($3 \leq C_f < 6$) of Zn contamination, ranked as LRM (5.15) > HRB (3.55) > MRB (3.04). Moreover, moderate levels ($1 \leq C_f < 3$) of contamination by

Table 6: Classification of contamination level based on contamination factor (C_f) and degree of contamination (C_{deg}) for heavy metals in rooftop dust on different building types.

Contamination factor (C_f)				
Heavy metal	**C_f index**	**Low-rise building (LRB)**	**Medium-rise building (MRB)**	**High-rise building (HRB)**
Cd	C_f value	2.80	2.10	1.57
	Contamination level	Moderate	Moderate	Moderate
Cr	C_f value	1.09	0.56	0.67
	Contamination level	Moderate	Low	Low
Cu	C_f value	2.61	1.76	1.36
	Contamination level	Moderate	Moderate	Moderate
Ni	C_f value	1.40	0.85	0.65
	Contamination level	Moderate	Low	Low
Pb	C_f value	3.34	2.34	2.76
	Contamination level	Considerable	Moderate	Moderate
Zn	C_f value	5.15	3.04	3.55
	Contamination level	Considerable	Considerable	Considerable
Degree of contamination (C_{deg})				
C_{deg} index		**Low-rise building (LRB)**	**Medium-rise building (MRB)**	**High-rise building (HRB)**
C_{deg} value		16.39	10.65	10.56
Contamination degree		Considerable	Considerable	Considerable

Cd and Cu were also prevalent across all building categories in this study.

Table 6 also presents the C_{deg} calculated for each building category. The results indicated that the C_{deg} was significantly higher in LRB (16.39), followed by MRB (10.65) and HRB (10.56). These C_{deg} values demonstrated a significant level of contamination ($10 \leq C_{deg} < 20$) in rooftop dust fall across all the building types examined in this study. The findings of this study align with previous reports on surface soils (Niraula et al., 2022) and dust samples from various land uses in the Kathmandu district (Shakya et al., 2019). Liu et al. (2011) identified Cr, Ni, Cd, Pb, As, and Cu as anthropogenic and geogenic elements in surface soils, emphasizing that their distribution patterns were generally invariant. Prolonged exposure to the dusty environment in the community may result in negative health impacts, particularly for children, pregnant women, and vulnerable elderly individuals (Du et al., 2013).

Pollution load index (PLI)

The pollution load index (*PLI*) represents the combined pollution effect on soil from various heavy metals. Figure 4 illustrates the estimated *PLI* values for rooftop dust deposition across three categories of buildings in this study.

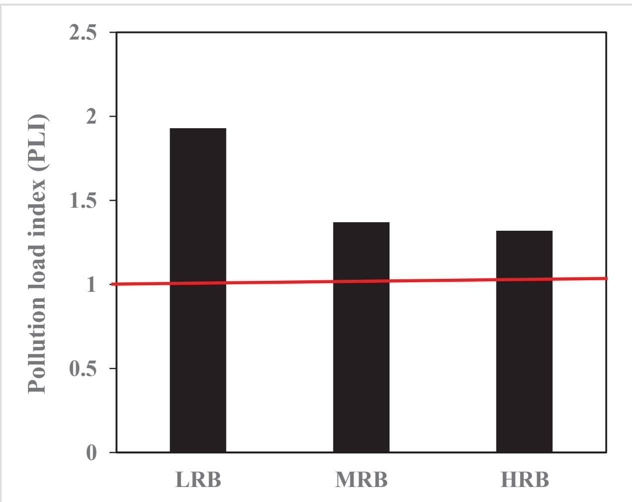

Figure 4: Pollution load index (*PLI*) for heavy metals in rooftop dust deposition on different building types.

Results revealed that the *PLI* values for the buildings were in the order of LRB (1.93) > MRB (1.37) > HRB (1.32). Since the *PLI* values exceeded the suggested threshold of 1.0, rooftop dust from all studied building categories was found to be polluted. The elevated *PLI* value could be attributed to the cumulative accumulation of heavy metals in rooftop dust, indicating an alarming condition in the study area with increased pollution levels. The higher *PLI* value in low-rise buildings (LRB) is mainly due to their proximity to direct emission sources such as traffic, road dust, and ground-level industrial activities, which contribute to greater deposition of heavy metals. In contrast, MRB and HRB are more affected by atmospheric transport of fine particles that are more widely dispersed and uniformly deposited at higher elevations. As a result, MRB and HRB show comparable *PLI* values, but generally lower than LRB due to their distance from ground-level sources. This pattern reflects typical heavy metal deposition mechanisms, where coarse particles settle rapidly near sources and fine particles are carried upward by wind and urban turbulence (Li et al., 2020; Wei & Yang, 2010). The results of this study are consistent with those of Roy et al. (2019), which similarly showed a high pollution load in the road dust of Delhi, India, as indicated by elevated *PLI* values. Additionally, the results of this study also align with Niraula et al. (2022), who reported elevated *PLI* values across various land uses in urban soils of Kathmandu, indicating the progressive soil deterioration from metal contamination.

Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) serves as a pollution indicator to assess the level and extent of anthropogenic contaminant deposition in surface soil (Barbieri, 2016). This index is calculated by normalizing a metal's concentration in the topsoil against the background concentration of the same element. The results indicated that the I_{geo} values varied among the selected HMs and building types (table 7).

The I_{geo} helps quantify and compare pollution levels of heavy metals on the rooftops of different building types in Kathmandu. Higher I_{geo} values on low-rise buildings, for instance, indicate a stronger influence from nearby ground-level pollution sources, while similar or lower I_{geo} values on high-rise buildings

Table 7: Geo-accumulation index (I-geo) for heavy metals in rooftop dust deposition on different building types.

Heavy metal	I_{geo} index	Low-rise building (LRB)	Medium-rise building (MRB)	High-rise building (HRB)
Cd	I_{geo} value	0.56	0.42	0.31
	Pollution degree	1	1	1
	Pollution level	Unpolluted to moderately polluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted
Cr	I_{geo} value	0.22	0.11	0.13
	Pollution degree	1	1	1
	Pollution level	Unpolluted to moderately polluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted
Cu	I_{geo} value	0.52	0.35	0.27
	Pollution degree	1	1	1
	Pollution level	Unpolluted to moderately polluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted
Ni	I_{geo} value	0.28	0.17	0.13
	Pollution degree	1	1	1
	Pollution level	Unpolluted to moderately polluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted
Pb	I_{geo} value	0.67	0.47	0.55
	Pollution degree	1	1	1
	Pollution level	Unpolluted to moderately polluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted
Zn	I_{geo} value	1.03	0.61	0.71
	Pollution degree	2	1	1
	Pollution level	Moderately polluted	Unpolluted to moderately polluted	Unpolluted to moderately polluted

may suggest reduced deposition or finer particle transport (Turekian & Wedepohl, 1961; Wei & Yang, 2010). In this study, the sum of all six I_{geo} values indicated that the levels of metal pollution in the dust falling on the buildings were in the descending order of LRB (3.28) > MRB (2.13) > HRB (2.10). Among the three building types, the LRB demonstrated comparatively higher I_{geo} values for all the examined heavy metals, in the order of Zn > Pb > Cd > Cu > Ni > Cr. The MRB and HRB exhibited the same sequence of heavy metals according to their I_{geo} values. Nevertheless, the I_{geo} values showed that all three building types, except for the LRB regarding Zn, remained within the unpolluted to moderately polluted range, indicating a first degree of pollution. The LRB was moderately polluted with Zn, showing a second degree of pollution. In this study, Zn demonstrated higher I_{geo} values across all building types, consistent with the findings of Song et al. (2022), which indicated elevated I_{geo} values for Zn in rooftop dust on buildings of various heights in China. Hence, the present study suggests that Zn is the primary contaminant in rooftop dust in the Kathmandu metropolitan area. Conversely, the I_{geo} index showed that Cd pollution was highest in atmospheric deposition in central urban areas of Chongqing, Southwestern China, as demonstrated in the study conducted by Zhang et al. (2020).

Conclusion

This study investigated the concentration and ecological risks of six heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in rooftop dust collected from low, medium, and high-rise concrete buildings in the Kathmandu metropolitan area. The findings indicate that building height significantly influences the deposition of heavy metals, with low-rise buildings showing substantially higher metal concentrations and pollution indices compared to medium and high-rise structures. This trend likely results from their closer proximity to ground-level emission sources, such as traffic, resuspended road dust, and local industrial activities, leading to greater contamination of rooftop dust in low-rise buildings. Among all the metals analyzed, Zn and Cu were consistently dominant, suggesting a strong association with anthropogenic activities like vehicle wear (brake and tire dust), construction, and metal processing. The Pollution Load Index (*PLI*), Contamination Factor (C_f), and Degree of Contamination (C_{deg}) confirmed that rooftop dust, particularly on low-rise buildings, is moderately to considerably polluted, posing potential environmental and public health concerns. Furthermore, the Geo-accumulation Index (I_{geo}) revealed unpolluted to moderately polluted conditions for most metals while highlighting moderately polluted levels of Zn in low-rise buildings, reflecting elevated urban metal loads. The strong correlation between Cr and Ni also indicates a common source, likely related to combustion or industrial emissions.

Overall, this research highlights the importance of urban form and building typology in influencing the distribution of heavy metals in atmospheric dust deposition. Given the potential for human exposure to toxic metals through inhalation, ingestion, or dermal contact with rooftop dust, particularly fine particles, regular monitoring and pollution source identification are essential. The findings provide a valuable baseline for policymakers and urban environmental planners aiming to manage air quality and reduce heavy metal pollution in urban areas. Future research should concentrate on assessing the non-carcinogenic and carcinogenic health risks associated with metal-contaminated rooftop dust, as well as identifying specific point and non-point sources that contribute to heavy metal enrichment in the Kathmandu Valley.

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Soil Quality Impacted by Brick Kilns in the Agriculture Fields of Kathmandu Valley

Melina Koirala, Ramesh Prasad Sapkota*, Sadhana Pradhanang Kayastha
Central Department of Environmental Science
Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal
*Correspondence: rsapkota@cdes.edu.np

Abstract

Brick kilns are causing environmental concerns due to their emissions and potential negative impacts on soil health and heavy metal accumulation in the agricultural soils. However, there are limited studies reflecting the impacts on agricultural soils due to the operation of brick kilns in the Kathmandu Valley, Nepal. Therefore, this study aims to assess the impact of the kilns on soil quality in Lalitpur and Bhaktapur districts of Kathmandu Valley, focusing on soil parameters pH, nitrogen, phosphorus, potassium, moisture content, organic carbon, and heavy metals (Pb and Zn). Standard methods were followed for the determination of soil quality parameters. Twelve brick kilns (six from each district) were studied, with 36 soil samples (0-15 cm depth) collected at 100 m, 200 m, and 300 m from each kiln. Results showed low levels of organic matter, carbon, nitrogen, potassium, and moisture near the proximity of the brick kiln areas, i.e., in most of the 100 m distance sites compared to 300 m sites. Soil excavation for brick production and kiln emissions are degrading agricultural land, gradually deteriorating key soil fertility over time. Lead (not detectable-32.04 mg/kg) and zinc (22.44-143.16 mg/kg) concentrations in the soil samples were in the commonly observed natural range, and the geo-accumulation index indicated low lead and high zinc contamination. Soil quality parameters were in improved conditions moving the distance from the kilns, suggesting the impact of emissions and nearby soil excavation for brick production. Alternatives to brick uses need to be identified for conserving the fertile top soils of the agricultural lands.

Keywords: *Geo-accumulation index, Kathmandu Valley, Physicochemical parameters, Soil fertility*

Introduction

Soil consists of minerals, organic matter, air, water, microorganisms, fractured rocks, and other constituents shaped by environmental reactions (Edori & Iyama, 2017). It serves as both sink and source for metals and other pollutants, making an essential indication of environmental quality (Karim et al., 2014). Apart from water and air, soil quality is one of the three components of environmental quality (Andrews et al., 2002). Soil is not only the key nutrient-bearing environment for plant life (Bradl, 2004) but also a supplier of many pollutants to plants because plants can uptake toxic substances through their roots from soils (Youssef & Chino, 1991). As the world's population grows, so does the demand for bricks for construction, establishing the brick business as a thriving industry (Skinder et al., 2014). Brick kilns reduce soil fertility by removing topsoil, directly impacting crop productivity and increasing nutrient restoration costs (Bisht & Neupane, 2015). Brick kilns deteriorate soil's physical, biological, and chemical properties, reducing fertility and productivity while depleting organic matter, making it unsuitable for farming (Thapa, 2011). Brick kilns release toxic gases that disrupt natural cycles, like the nitrogen cycle, leading to reduced fertility and nutrient depletion in the soils (Krishna & Govil, 2007). Pollutants like heavy metals, CO, CO_2, SO_2, nitrogen oxides, and VOCs are especially concerning due to their toxicity, non-biodegradability, and buildup over time (Kayastha, 2014). Metals from bottom ash and fly ash around brick kilns spread to nearby soil, altering its structure (Sikder et al., 2016). In recent years, the number of brick kilns in the Kathmandu Valley has grown significantly due to urbanization and higher demand for building materials (Thapa, 2011). Improved knowledge of the soil mining system used to supply brick kilns may reveal options for minimizing the impact on yields from agriculture (Biswas et al., 2018).

Brick kilns have become a serious environmental issue especially in developing countries (Dey & Dey, 2017). In Nepal, 96% of kilns are outdated and use energy intensive and highly polluting technologies causing harmful impacts on health and agricultural yields (from nitrogen oxide) locally and contribute to global warming (Vista & Gautam, 2018) and are mainly concentrated around Kathmandu Valley and in Terai regions. Few studies have been conducted in Nepal to show that brick kilns are responsible for contaminating the environment, the majority of which are based on the measurement of air polluting elements. This study aims to understand the impact of brick kilns on agriculture soils, focusing on soil quality parameters, in the Lalitpur and Bhaktapur districts of Kathmandu Valley.

Materials and methods

Study area

This study was carried out in Kathmandu Valley which lies in Bagmati Province, Nepal. For this study, Lalitpur District and Bhaktapur District of Kathmandu Valley were selected as the study sites (Fig. 1). Lalitpur District is situated in the south-central part of Kathmandu Valley at an altitude of about 1,400 m. It spans 385 km^2 and experiences a relatively moderate temperature with evenly distributed precipitation (MoHA, 2025a). Bhaktapur District, located in the eastern part of Kathmandu Valley, is the smallest district in Nepal, covering an area of 119 km^2 (MoHA, 2025b). The climate in Bhaktapur is characterized by subtropical and temperate conditions.

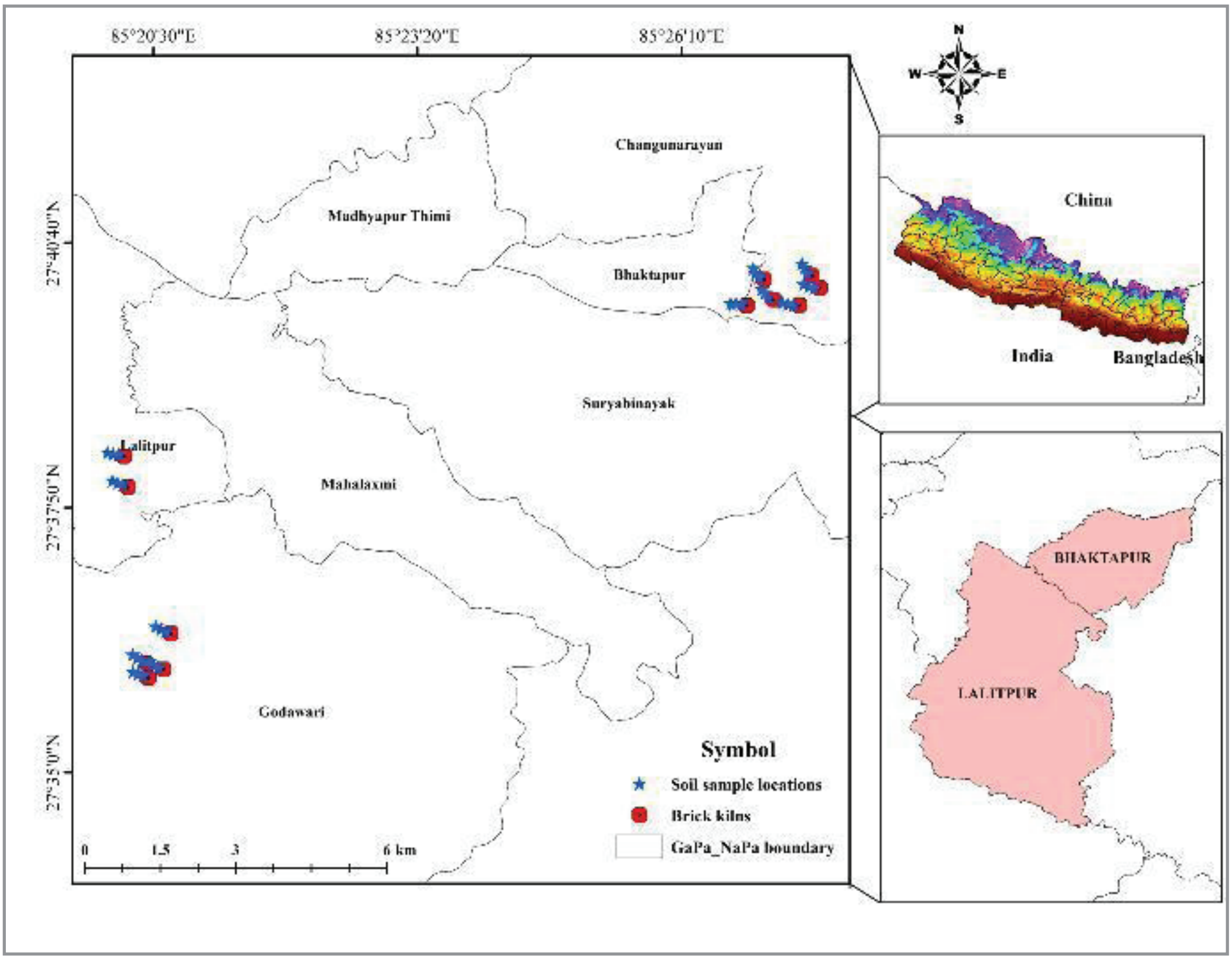

Figure 1: Study area map showing the locations of brick kilns and sampling points

Bhaktapur and Lalitpur districts of Kathmandu Valley have large number of brick kilns along the highly agricultural fields. Sampling sites were in Chapagaun and Harisiddhi of Lalitpur District, as well as Tathali and Faidhoka of Bhaktapur District. The selection of brick industries for this study was done based on the presence of agricultural land nearby the kiln area. Twelve brick kilns were selected for the study i.e. six brick kilns each from Lalitpur and Bhaktapur districts.

Methods

Soil samples collection

Soil samples were collected nearby the brick kilns areas, which were in operation for more than ten years, and are in operation in present condition for at least one month. Soil samples from Lalitpur District were collected in January, 2023 whereas, samples from Bhaktapur District were collected in March, 2023 which is the peak period of brick production. Thirty-six (eighteen samples from each district) soil samples (0-15cm depth) were collected from twelve different brick kilns from three points of each kiln area to see the changes with distance to agriculture field. The distances are approximately 100 m, 200 m, and 300 m from the kilns toward the agricultural field (Bisht & Neupane, 2015; Ismail et al., 2012; Rajonee et al., 2018). Each of the samples collected at the site were placed in a closed plastic bag and labeled as needed and the GPS location was taken. External contaminants were removed and the samples were air-dried in room temperature for further laboratory analysis. The soil sample was collected in the west direction from each kiln sites according to the wind direction shown in the wind rose diagram of Kathmandu Valley (Aryal et al., 2008). The collected soils were air dried for one week in room temperature and grinded to a fine powder which were later sieved through 250 µm stainless steel mesh wire. The samples were then stored in a polythene container to make ready for the analysis.

Soil analysis

The collected soils were air dried for one week in room temperature and grinded to a fine powder which were later sieved through 250 µm stainless steel mesh wire. The samples were then stored in a polythene container ready for the analysis. The soil samples were further analyzed using standard methods (Table 1).

Statistical and geo-accumulation analysis

Statistical analyses for this study were one-way ANOVA, Tukey HSD as a post hoc test, and Pearson's correlation. The significance level considered for this study was 0.05. The purpose of the one-way ANOVA was to assess the variability of soil quality parameters across different distances. Similarly, the Tukey HSD test was used to examine the mean differences in the concentration of soil quality parameters between distances. Additionally, Pearson's correlation test was performed to investigate the relationships between the soil quality

Table 1: Methods and instruments used for the analysis of soil samples

S.N.	Parameter	Method	Instrument	References
1	pH	Electrometric method	pH meter YSI 1200 (China)	Jackson (1973)
2	Electrical conductivity	Electrometric method	Conductivity meter 4200 Jenway 4200 (UK)	Jackson (1973)
4	Potassium	Flame photometry	Flame photometer model 1382 (India)	Toth and Prince (1949)
5	Phosphorous	Spectrophotometric Brays II method	Spectrophotometer model SSI UV 2102	Olsen et al. (1982)
6	Nitrogen	Kjeldhal method		Jackson (1973)
7	Organic matter	Walkley-Black method		Walkley and Black (1934)
8	Lead, Zinc	Wet digestion and Atomic Absorption Spectrometry	AAS, HG 3000 (Australia)	USEPA (1986)
9	Moisture	Gravimetric	Digital weighting balance	Weight of fresh and dry soil samples

parameters. The data collected were analyzed using Microsoft Excel 2013 and R (R Core Team, 2016).

The geo-accumulation index (Igeo) was calculated using the following formula developed by Muller (1969).

$$Igeo=\log_2 \frac{Cm}{1.5Bm}$$

Where Cm is the concentration of the studied metals in the soil and Bm is the background value of the same metal. Factor 1.5 is used to account for the possible variations in the background values. The world average concentration of metals reported for shale served as a background value in this study (Turekian & Wedepohl, 1961). For the not detectable value of lead in soils samples, to calculate Igeo, we have considered 0.05 as a reference minimum value. Different values of the Igeo indicate a total of seven grades or classes of contamination level: Class 0 (nearly uncontaminated): Igeo< 0; Class 1 (uncontaminated to moderately contaminated): 0 <Igeo< 1; Class 2 (moderately contaminated): 1 <Igeo< 2; Class 3 (moderately to severely contaminated): 2 <Igeo< 3; Class 4 (severely contaminated): 3 <Igeo< 4; Class 5 (severely to extremely contaminated): 4 <Igeo< 5; and Class 6 (extremely contaminated): 5 <Igeo.

Results and discussion

Soil pH

pH value of soils from agricultural fields ranged from 5.2 to 8.5 (Fig. 2), describing that samples are acidic to alkaline in nature (NARC, 2013). Bisht and Neupane (2015) studied the soil around brick kilns of Bhaktapur District and found that pH values range from 5.8 to 7.6 which was consistent to our study. Akter et al. (2016) showed that the pH values of the samples ranged from 4.9 to 7.7 represents that the samples in the studied area were very strongly acidic, slightly acidic, neutral, and slightly alkaline in nature. Higher pH values represented the appropriate range for plant growth, while lower pH levels prevented proper plant growth (Yaseen et al., 2015). The one-way ANOVA revealed that there is an increasing trend ($p < 0.05$) in soil pH as the distance from the brick kiln increases. A study conducted by Rajonee et al. (2018) found that pH values of the samples ranged from 6.9 to 8.8 indicating very slightly acidic to strongly alkaline (Rajonee et al., 2018).

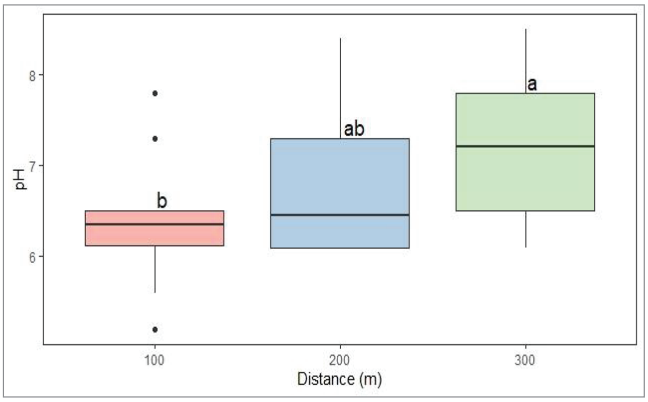

Figure 2: Variation in soil pH with distance from brick kilns where the letters 'a' and 'b' indicate significant differences between groups as determined by the Tukey HSD test

The results for electrical conductivity ranged from 43 µS/cm to 579 µS/cm in the study area. Cations can be accumulated in farm soils due to various agricultural techniques like irrigation, fertilizer, and other practices. However, the brick dust produced by the brick kiln activities decreased the soil's cationic composition (Saha et al., 2021). The analysis results obtained by Yaseen et al. (2015) showed that the EC were found to be ranged 120 µS/cm –527 µS/cm in different sites of Raniganj Coal Field. Saha et al. (2021) found that the EC of collected farm soil samples ranged from 165 to 391 µS/cm in Rajshahi and 222 to 453 µS/cm in Gazipur.

Soil organic matter

The organic matter content ranged from 0.4% to 2.8% in this study (Fig. 3). The mean value of organic matter in study area showed low concentration in comparison with NARC (2013). Burning of organic carbon in the brick kiln, the intense heat in the kiln area, and the topsoil removal practices could be the contributing factors for the low organic matter (OM) content (Saha et al., 2021). A study conducted by Yaseen et al. (2015) revealed that the organic matter of soil in the studied areas varied between 0.5% to 3.5% with an average value of 1.76% (Yaseen et al., 2015). Chowdhury and Rasid (2021) found that organic matter ranged from

0.60% to 1.67% respectively under agriculture soils near the brick kilns. The reduced cation exchange, water retention capacity and buffering abilities of the soil are due to lower levels of organic matter. It is subject to decreased biological activity and soil degradation (Van Loon, 2007).

The one-way ANOVA suggests that there is an increasing trend ($p < 0.05$) in organic matter as the distance from the kiln area increases. This trend could be attributed to factors such as soil excavation from the nearby area for brick production and the emissions released by the brick kilns affecting the agricultural land in close proximity. A study from Bhaktapur revealed that the organic matter of soil in the studied area were varied between 0.47% and 1.60% (Bisht & Neupane, 2015). Likewise, the organic matter content in the collective farm soil samples was ranged from 0.58% to 3.21% in Rajshahi and 0.34% to 1.47% in Gazipur (Saha et al., 2021).

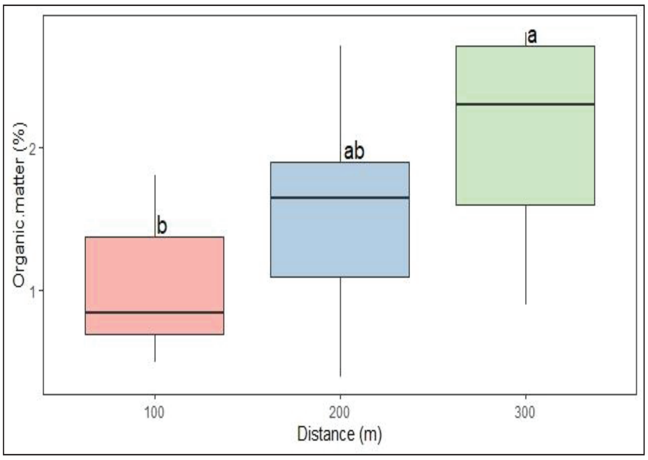

Figure 3: Variation in organic matter concentration with distance from brick kilns where the letters 'a' and 'b' indicate significant differences between groups as determined by the Tukey HSD test

Soil organic carbon

Good fertility is indicated by an organic carbon concentration more than 0.75% (Yaseen et al., 2015). The soil organic carbon in our study ranged from 0.2% to 1.6% with a mean concentration of 0.9% (Fig. 4). The range of organic carbon were nearly similar to the study conducted by Rajonee et al. (2018), with the range from 0.2% to 1.4%. The one-way ANOVA test suggests that as the distance from the kiln area increases, there is an observed increase in organic matter ($p < 0.05$), which in turn influences the concentration of organic carbon in the soil. According to Akter et al. (2016), organic carbon enhances soil structure, improves aeration and water absorption, increases the capacity for water retention, and provides essential nutrients for plant growth. Organic carbon of the soil ranged from 0.13% to 1.15% in a study done by Akter et al. (2016), whereas it ranged from 0.28% to 0.93% in the study conducted by Bisht and Neupane (2015).

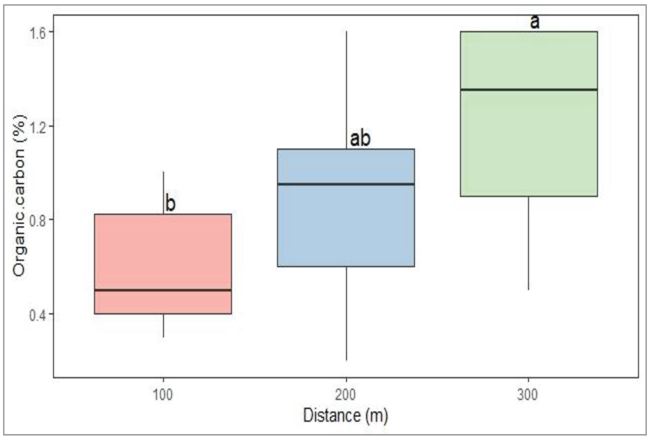

Figure 4: Variation in organic carbon concentration with distance from brick kilns where the letters 'a' and 'b' indicate significant differences between groups as determined by the Tukey HSD test

Soil moisture

The soil moisture ranged from 10.8% to 43.6%, with a mean value 21.47% (Fig. 5) in our study. The mean values of soil moisture were observed higher than the value revealed by Yaseen et al. (2015) which was 4.2%. The one-way ANOVA suggests that there is an increasing trend in soil moisture as the distance from the kiln area increases ($p < 0.05$). According to Mazumdar et al. (2018), the heat released during brick burning lowers the soil moisture in adjacent areas. A similar scenario may have occurred in our study as well. In a study conducted by Rajonee et al. (2018) revealed that soil moisture content ranges from 18.77% to 56.49%. The amount of moisture in the soil contributes to determining the soil's quality. Crop development, decaying patterns, and a soil's ability to deliver water to crops throughout dry spells are all influenced by its water holding capacity (Debnath et al., 2012).

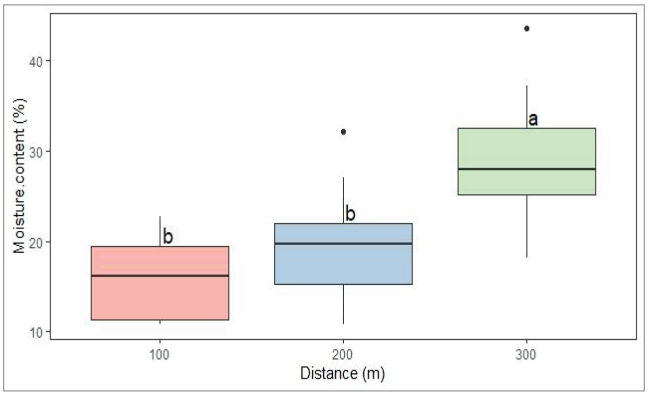

Figure 5: Variation in moisture content with distance from brick kilns where the letters 'a' and 'b' indicate significant differences between groups as determined by the Tukey HSD test

Total nitrogen in soil

The value of total nitrogen ranged from 0.01% to 0.13% with the mean value of 0.02%, 0.035% and 0.04% at distances of 100 m, 200 m and 300 m, respectively (Fig. 6) which lies in very low concentration in comparison to NARC (2013). Low value of organic matter in the study area may be the cause of the low nitrogen content. In the farming soils adjacent to the cluster of brick kilns, total nitrogen levels varied from 0.10% to 0.23%, respectively as studied by Chowdhury and Rasid (2021) which was higher than our study.

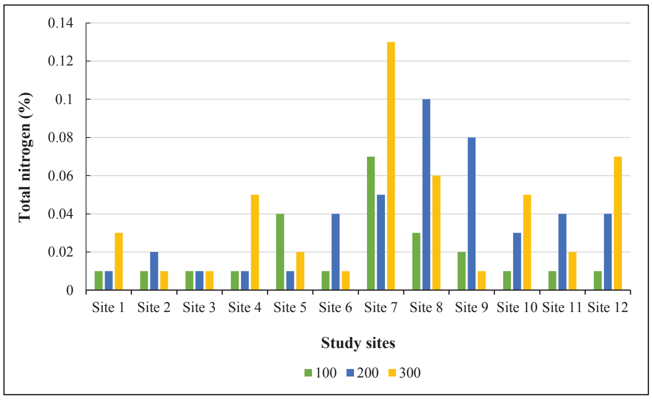

Figure 6: Variation in nitrogen concentration with distance from brick kilns

Available phosphorous in soil

The concentration of phosphorous was ranged from 13.99 kg/ha to 59.06 kg/ha with the mean concentration of 35.26 kg/ha, 39.26 kg/ha, 35.86 kg/ha at distances of 100 m, 200 m and 300 m, respectively in our study (Fig. 7). The mean concentration of phosphorous in study area showed medium concentration in comparison to NARC (2013). The value of available phosphorus ranged from 13.23 kg/ha to 43.3 kg/ha in a study conducted by Dey and Dey (2017) which was slightly lower in comparison to our study. Phosphorus has been regarded as 'Master Key to Agriculture' (Dey & Dey, 2017).

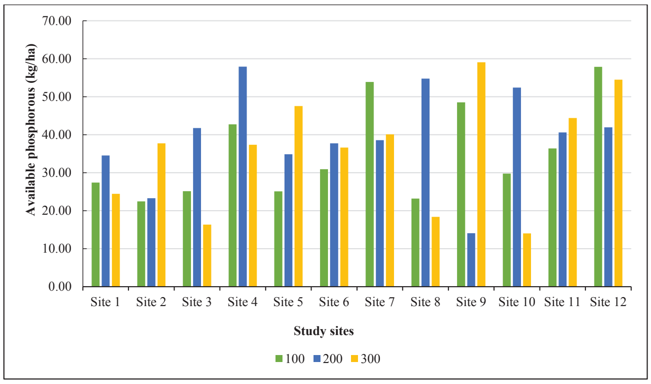

Figure 7: Variation in available phosphorous with distance from brick kilns

Available potassium in soil

The concentration of potassium ranged from 29.57 kg/ha to 220.42 kg/ha with the mean concentration of 62.50 kg/ha, 94.75 kg/ha, 100.58 kg/ha at distances of 100 m, 200 m and 300 m, respectively in our study (Fig. 8), which showed the low concentration in comparison to NARC (2013). The value of available potassium ranged from 49.7 to 170 kg/ha in a study conducted by Dey and Dey (2017).

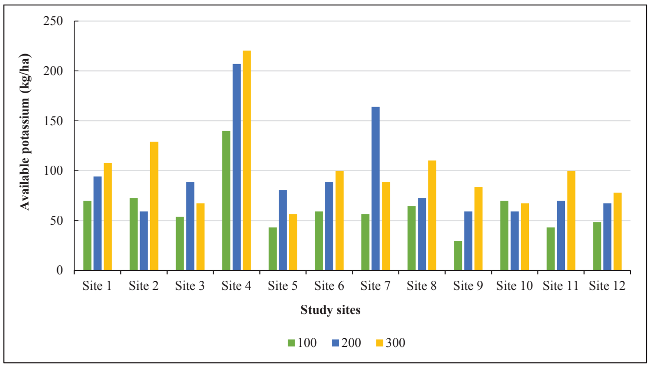

Figure 8: Variation in available potassium with distance from brick kilns

Lead concentration in soil

The Pb concentration ranged from not detectable to 32.04 mg/kg range in the sites, reflecting the maximum concentration observed within the limit for the common range of soils (2-200 mg/kg) (Lindsay, 1979). The extremely hazardous heavy metal lead (Pb) disrupts a number of physiological processes in plants, destroys lipid membranes, which in turn harms chlorophyll and the photosynthesis process while also inhibiting plant growth (Najeeb et al., 2014). A study conducted by Saha et al. (2021) revealed that the Pb concentration in farm soil ranged from 9.53 to 31.27 mg/kg in Rajshahi and 9.54 to 23.86 mg/kg in Gazipur. The concentration of lead ranged from 19.07 to 52.07 mg/kg in a study conducted by Chowdhury and Rasid (2021), whereas it was in a range of 5.45 to 11.82 mg/kg in a study conducted by Bisht and Neupane (2015) in Bhaktapur District which is higher in comparison to our present study of Bhaktapur.

Zinc concentration in soil

Zn is essential to function as a source of nutrition for both people and crop plants. However, it also performs extremely dangerous to plants and fauna when present in higher concentrations (Saha et al., 2021). It was observed that zinc concentration ranged from 22.44 to 143.16 mg/kg with the mean concentration of 49.47, 58.72, and 50.81 mg/kg at distances of 100 m, 200 m, and 300 m, respectively (Fig. 10), which is in limit compared to the content in the common range of soils (10-300 mg/kg) (Lindsay, 1979). Zn concentration in farm soil ranged from 12.68 to 79.34 mg/kg in Rajshahi and 11.24 to 78.51 mg/kg in Gazipur (Saha et al., 2021). The low pH might be responsible for increasing Zn concentration (Saha et al., 2021).

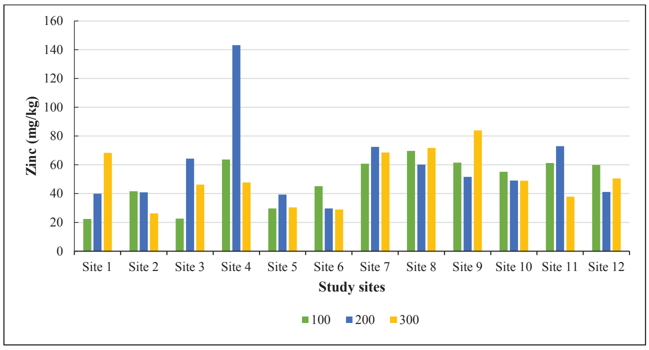

Figure 10: Variation in zinc concentration with distance from brick kilns

Correlation between physicochemical parameters including heavy metals

Pearson correlation analysis revealed that soil nitrogen positively correlates with electrical conductivity, organic matter, and organic carbon. Nitrogen boosts crop yields, increasing plant residues and enhancing soil organic carbon and organic matter (Powlson et al., 2011). Organic matter releases mineralizable nitrogen, creating a strong link between organic carbon and available nitrogen, resulting in a positive correlation (Kumar et al., 2014). Electrical conductivity influences crop yields, suitability, and nutrient availability, with soil salinity significantly impacting EC levels (Saha et al., 2021). Soil organic matter showed a strong positive correlation with organic carbon, meaning both increase together. Soil moisture also correlated positively with organic matter and organic carbon. Zinc was positively linked to phosphorus and potassium, while lead showed a negative correlation with nitrogen, indicating higher lead levels reduce nitrogen concentration (Table 2).

Table 2: Correlation of physicochemical parameters along with heavy metals

	pH	EC	OM	OC	N	P	K	SM	Zn
pH	1								
EC	0.083	1							
OM	0.207	0.154	1						
OC	0.198	0.13	0.997**	1					
N	-0.218	0.367*	0.367*	0.353*	1				
P	0.103	0.092	0.117	0.124	0.047	1			
K	0.073	-0.196	-0.044	-0.048	0.022	0.154	1		
SM	0.142	-0.125	0.561**	0.570**	0.16	0.084	0.24	1	
Zn	-0.142	0.107	-0.013	-0.022	0.155	0.357*	0.405*	-0.2	1

*** Correlation is significant at the 0.05 level (2-tailed).**

**** Correlation is significant at the 0.01 level (2-tailed).**

Table 3: Geo-accumulation index for lead and zinc

Igeo Value	Igeo Class	No. of samples for Lead	No. of samples for Zinc	Designation of soil
>5	6	_	4	Extremely contaminated
4-5	5	_	25	Heavily to extremely contaminated
3-4	4	_	7	Heavily contaminated
2-3	3	_	_	Moderately to heavily contaminated
1-2	2	_	_	Moderately contaminated
0-1	1	1	_	Uncontaminated to moderately contaminated
0	0	35	_	Practically uncontaminated

Contamination degree based on geo-accumulation index

The geo-accumulation index of overall study sites (i.e. sites from both Lalitpur and Bhaktapur) was prepared using Muller (1969) in which 35 soil samples showed practically uncontaminated status and only 1 sample showed uncontaminated to moderately contaminated status in terms of lead. In case of zinc, 4 samples showed extremely contaminated, 25 samples showed heavily to extremely contaminated, 7 samples showed heavily contaminated status.

Ravankhah et al. (2017) found that the Igeo value of Pb in soils were moderately contaminated by Pb. The Igeo value for Zn in soil samples were moderately polluted whereas in our study it was heavily contaminated in most of the samples. Fig. 12 shows the range and average value of Igeo values for lead and zinc, using background values.

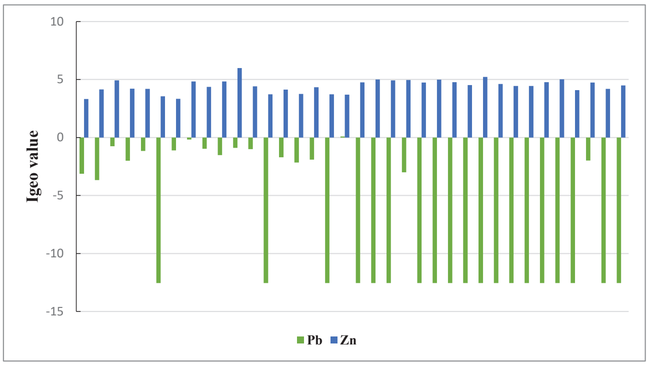

Figure 12: Range and average of Igeo value for lead and zinc.

Conclusion

The study determined that the soil in Lalitpur and Bhaktapur districts of Kathmandu Valley ranged from acidic to alkaline soils, with low fertility parameters and medium phosphorus levels. Soil pH, organic carbon, organic matter, and moisture varied significantly with distance from brick kilns. Lower values of these parameters were observed in most of the samples near the brick kiln areas. Most samples showed low lead contamination but high zinc contamination based on the geo-accumulation index. Lead and zinc were within common range for soils. Soil excavation for brick production and kiln emissions are degrading agricultural land, gradually harming the key soil fertility parameters over time. Comprehensive monitoring of brick kiln emissions and dispersion of pollutants are suggested for future assessments.

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Web Application Prototype on Air Quality Index Prediction, Monitoring, and Information Dissemination System: Machine Learning and Python-Streamlit-based Application Tailored for Kathmandu Metropolitan City

Reyan Kumar Sapkota[1,*], Narayan Adhikari[1], Chiranjivee Subedi[1], Riya Jha[2], Manoj Subedi[1]
[1]Department of Civil Engineering, Institute of Engineering, Pulchowk Campus.
[2]Department of Electrical Engineering, Institute of Engineering, Pulchowk Campus.
Correspondence: 079bce137.reyan@pcampus.edu.np

Abstract

Air pollution has become a critical issue in Kathmandu Valley, significantly impacting public health and daily life. Rising vehicular emissions, industrial activities, and insufficient environmental regulations have resulted in dangerously high Air Quality Index (AQI) levels. Residents frequently experience poor air quality, yet they lack easy and organized access to location-wise early AQI information and alerts, making it challenging for citizens and local governments to make informed decisions about their health and activities. Kathmandu Metropolitan lacks an integrated real-time Air Quality Index tracker and forecast-based IT application system, further highlighting the urgency of developing such an application. This paper proposes a web application prototype (Wolmann, 2023) tailored for Kathmandu Metropolitan City to predict, monitor, and disseminate information about the air quality index (AQI). The application prototype integrates three regression-based machine learning models (Random Forest Regressor, CatBoost Regressor, and Gradient Boosting Regressor) to provide accurate AQI predictions. It also includes an intuitive user interface (UI based on Python-Streamlit) that allows the admin side of KMC to fetch accurate AQI predictions/visualizations, disseminate personalized recommendations/email alerts for residents and the federal government, and allow station-wise mapping on Kathmandu Metropolitan City's map (using Python-Folium). Our ML Model achieved the R^2 values of 0.86, 0.87, and 0.93 for the Gradient Boosting Regressor, CatBoosting Regressor, and Random Forest Regressor, respectively.

Keywords: *CatBoost Regressor, Folium, Gradient Boosting Regressor, Streamlit, Random Forest Regressor.*

Introduction

Air pollution in Kathmandu Valley has reached alarming levels due to rising vehicular emissions, industrial activities, and insufficient environmental regulations. This study addresses the lack of an integrated real-time Air Quality Index (AQI) tracking and forecasting system in Kathmandu. The proposed web application leverages machine learning algorithms to predict AQI levels, provide real-time alerts, and disseminate information to residents and policymakers. The application also aligns with Kathmandu Metropolitan City's goals for environmental monitoring and public health awareness, contributing to SDG 11 (Sustainable Cities and Communities).

Kathmandu Metropolitan City (KMC) has recently begun the installation of Air Quality Monitoring Stations to extract the $PM_{2.5}$ (Particulate Matter of 2.5µg) concentration to assess the air quality of desired hotspots of Kathmandu Valley. Utilizing the raw data points collected by the station, appropriate ML and Neural Network-based models could be trained to develop an accurate forecasting system. Some well-known Machine Learning algorithms include Support Vector Machine (SVM), CatBoost, Gradient Boost, Logistic Regression, Decision Trees, K-Nearest Neighbors Algorithm, Random Forest Algorithm, etc. Suitable ML models need to be selected, depending on the nature of the dataset (i.e., Classification type vs Regression type). To predict the AQI using regression-based ML models, the data of independent features is fitted to predict the target value. In this paper, our target value is our AQI, and the independent features are month, day, hour, relative humidity, precipitation, pressure, windspeed, temperature, and dew point. Upon literature review, we preliminarily concluded that AQI has a high correlation with the above parameters. For better data fitting for a large number of training data and more features, deep learning models could also be applied. Deep learning automatically performs feature extraction and modeling following data training, whereas machine learning requires data scientists or users to do it (Zhang, 2023).

For User Interface, any front-end frameworks (like React, Angular, or Vue) could be employed. Similarly, for backend handling, there are already plenty of options like Python's Flask, FastAPI, etc. For our prototype, we've used Python's Streamlit library to prepare the admin-based UI due to Streamlit being tailored particularly for such data science applications. For data visualization, Matplotlib has been used. Similarly, Python's Folium library has been used for mapping forecasted AQI of desired stations.

Materials and Methods

Data Collection and Feature Engineering

Globally, the US government installs air monitoring devices in cities of their respective embassies and consulates to monitor the particulate matter concentrations of those towns/zones. As a part of this program, the US Embassy has placed two Air Monitor Devices in Nepal: one inside the US Embassy (Maharajgunj) and another in Phora Durbar. These devices collect data about the particulate matter ($PM_{2.5}$) and Ozone concentrations and convert them to respective AQIs. These data are recorded hourly and exported in a CSV file. The final datasets for both stations (US Embassy and Phora Durbar) are found on airnow.gov and we've used these authentic datasets for training our machine-learning-based AQI prediction Model. The datasets from 2017 to the present (with around 8000 spreadsheet rows in each year's dataset) are made publicly available on airnow.gov (AirNow, 2024).

The dataset for training the machine learning models includes hourly AQI values based on $PM_{2.5}$ pollutants from the past seven years, sourced from the U.S. Embassy in Kathmandu (AirNow, 2024).

Upon literature review, we concluded that the value of the Air Quality Index primarily depends upon nine major factors: month, day, hour, relative humidity (Zender-Swiercz, 2024), precipitation (Wang, 2023), pressure, windspeed (Purnomo, 2024), temperature (Zender-Swiercz, 2024), and dew point. In the data science community, the factors on which the magnitude of our predicted value depends are called Features and our to-be-predicted quantity is called Target. In our project, the Features are: month, day, hour, relative humidity, precipitation, pressure, windspeed, temperature, dew point, and windspeed, and the Target is the Air Quality Index.

The corresponding hourly values of those historical weather parameters (month, day, hour, relative humidity, precipitation, pressure, windspeed, temperature, and dew point) were extracted using Python's Open-Meteo library.

The raw data with hourly $PM_{2.5}$-based AQI values (from 2017 to 2024) was downloaded from www.airnow.gov. Since the AQI value depends mainly on Temperature, Pressure, Relative Humidity, Dew Point, and Precipitation (Rahman, 2024), we extracted the values of these parameters from 2017 to 2024 (on an hourly basis) using Python's OpenMeteo library. The values were extracted as data frames and later converted to CSV Files. Then, missing rows and rows with negative (broken data) values from the initial dataset (downloaded from ainow.gov) were deleted. Then, the newly generated data (with the above parameters like Temperature, pressure, relative humidity, etc.) and the initial dataset (downloaded from airnow.gov (AirNow, 2024)) were merged. This merged final dataset was used to train the machine-learning models. Python's Pandas library was perfectly reliable in performing the above data engineering/pre-processing process.

Training Machine Learning Models

To predict the AQI values of those 2 stations, we've trained 3 machine learning algorithms. The three algorithms are Gradient Boosting Regressor, CatBoost Regressor, and Random Forest Regressor. These three algorithms have been imported from Python's Scikit Learn (also called sklearn library)

First, the outliers were removed from the final merged dataset to ensure better fitting in the ML model. Then, that dataset was divided into two sections: X and Y. X is the data frame with the dependent features as major headings. The headings are Month, Day, Hour, Temperature, Relative humidity, precipitation, wind speed, Dew Point, and Pressure. Y is the data frame with the corresponding AQI value. In Y, "AQI_value" is the only heading. X and Y were split into 80% and 20%. 80% of X was chosen as X_train, and 20% was X_test. Similarly, 80% of Y was chosen as Y_train, and 20% was Y_test. The machine learning algorithm will now train (or fit the dataset on its regression lines/ planes in a process called Data fitting) on X_train and Y_train. X_test and Y_test will be utilized for checking the model's learning and prediction performance.

After splitting, the data was scaled using the StandardScalar method of Scikit Learn:

The data was fitted respectively for all three algorithms with their respective unique hyperparameters. The data was fitted with the following hyperparameters. Hyperparamters used are described in the annex.

In addition to the Standard Scaler, polynomial feature enhancement was applied to the Random Forest Regressor to increase the number of dependent features (X) and improve data fitting and prediction accuracy.

After data fitting with suitable hyperparameters, the model was used for prediction.

As per Python's OOP fundamentals, the fitted ML model is a Class. This class has a method called "predict". Using this method, we can pass our Dependent features as arguments to the model. Based on these arguments, the model class' **predict()** method returns our AQI value. After training the ML model, we converted it to a pickle file using Python's Pickle library. This readily available pickle file would later be used to create predictions.

Web Application

The web application was developed using Python's Streamlit library, providing an intuitive user

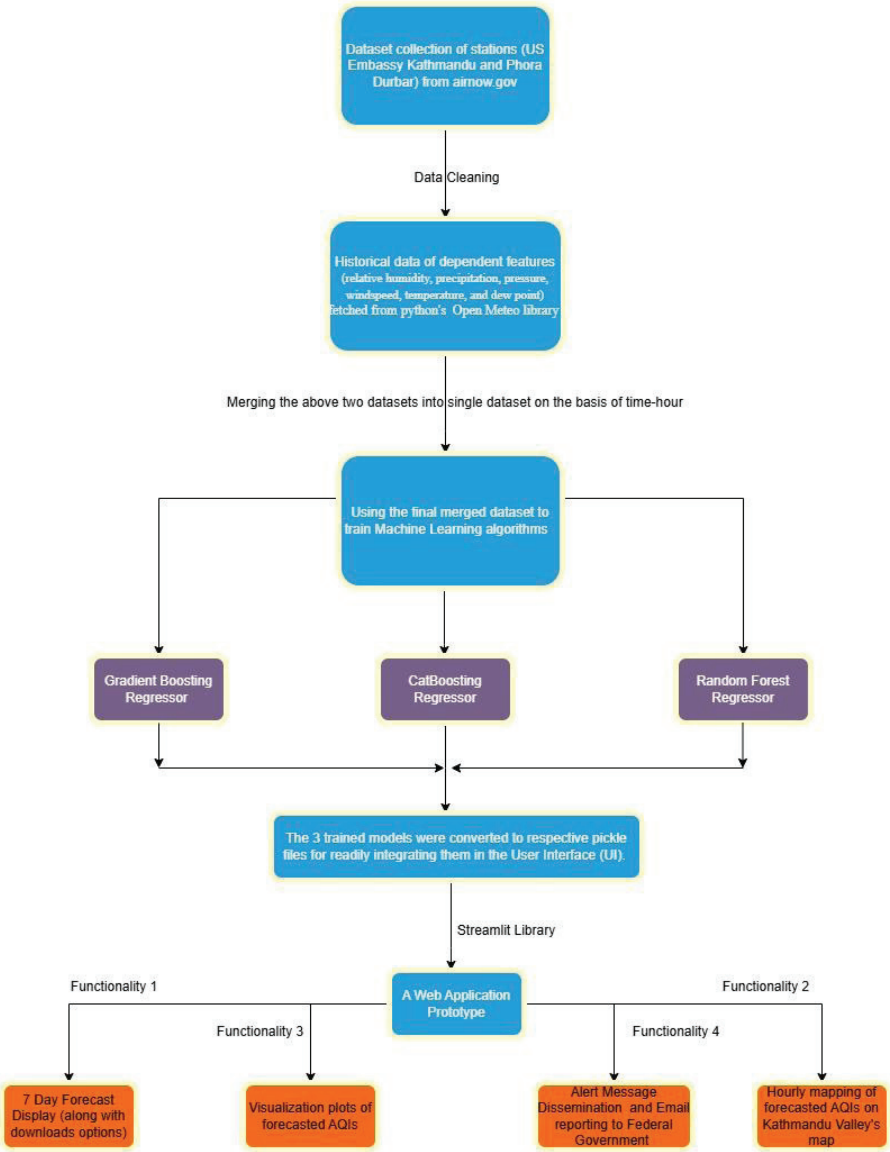

Figure 1: Flowchart depicting the entire workflow of the application.

interface for AQI predictions, visualizations, and alerts. The application also includes features such as a citizen alert system, a government reporting system, AQI trends visualization using charts, and mapping on Kathmandu Valley's map using Python's Folium library.

Results and Discussion

Model Performance

The Random Forest Regressor outperformed the other models, likely due to its ability to handle complex interactions between features and its robustness to overfitting. Polynomial feature enhancement further improved the model's accuracy by capturing non-linear relationships in the data.

The following performance metrics were tested

a. Mean Square Error, $MAE = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i|$

Where,

$y_i = real\ i^{th}\ value$

$\hat{y}_i = predicted\ i^{th}\ value$

$n = number\ of\ data$

MAE represents the average absolute error in AQI points and is dimensionless.

b. *Coefficient of Determination*, $R^2 = 1 - \frac{\Sigma(y_i - \hat{y}_i)^2}{\Sigma(y_i - \bar{y}_i)^2}$

where,

$y_i = real\ i^{th}\ value$

$\hat{y}_i = predicted\ i^{th}\ value$

$\bar{y}_i = mean\ of\ all\ values$

c. Root Mean Square Error, $RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}$

Where,

$y_i = real\ i^{th}\ value$

$\hat{y}_i = predicted\ i^{th}\ value$

$n = number\ of\ data$

RMSE represents the square root of the average squared error in AQI points and is also dimensionless.

Application Functionalities

We have added the following functionality to our web application. We've meticulously tried to tailor the application prototype of a web app exclusively for Kathmandu Metropolitan City's administrative purposes. Due to the availability of large volume datasets of Maharajgunj and Phora Durbar only, we have those two stations incorporated in our prototype. To achieve this goal, we've added the following functionalities/services to our prototype:

7-Day Hourly Forecast

In the UI shown below (Figure 2), each button returns the desired day's AQI prediction (done by all three algorithms) (Figure 2). Furthermore, a feature for downloading the forecast CSV has also been added (Annex).

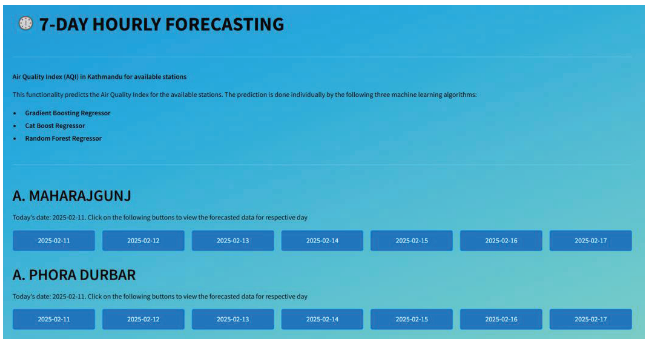

Figure 2: 7-Day Hourly Forecasting for Maharajgunj and Phora Durbar

Table 1: Model Performance Metrics

Performance Metric	Gradient Boosting Regressor	CatBoost Regressor	Random Forest Regressor
Coefficient of Determination	0.88	0.87	**0.94**
Mean Absolute Error	11	13	**9**
Root Mean Square Error	16	17	**13**

Citizen Alert System

The AQI values predicted from respective ML models were used to generate alert messages. The alerts were divided into four titles: Highest AQI and its time of occurrence (as predicted by each ML model), Health Alert, Hazard Description, and Caution (Annex). The automated message flex was designed using HTML and CSS.

Govt. Reporting System

Using a similar concept as above, a Federal Government Reporting System is also added. The required day's recommendation can be generated/automated and emailed to the central government with the click of a button (Annex). Along with the HTML and CSS designed message, the CSV files of each ML model's 7-day (hourly) forecasted dataset are also emailed. Python's powerful email.mime library has been utilized.

Mapping of AQI of 2 stations in Kathmandu

Python's Folium library allows us to import the maps of the desired coordinate range. On this map, we've mapped the AQI values of the 2 stations. Index color has been assigned. This color (or legend) depends on the severity of the Air Quality Index value. Mapping for the respective date (Figure 3) would allow the Kathmandu Metropolitan City to have live data updates of the air quality of the given stations (Figure 4). This could help the metropolitan disaster control unit to launch mitigating actions accordingly.

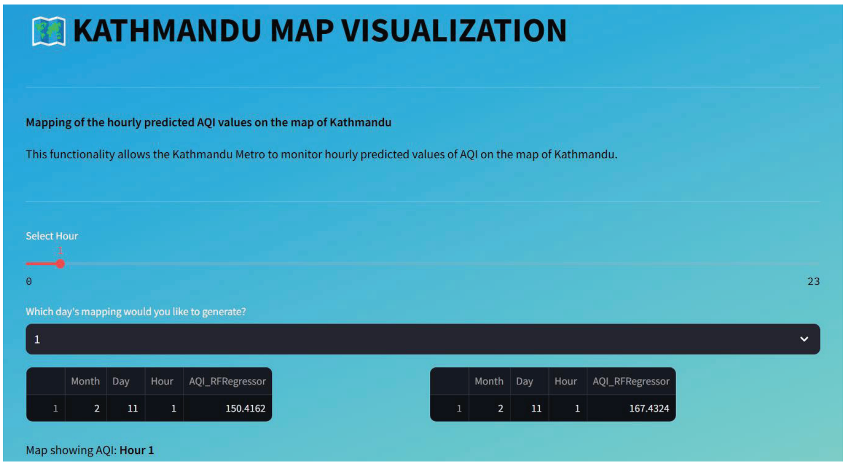

Figure 3: Mapping for the desired day and hour.

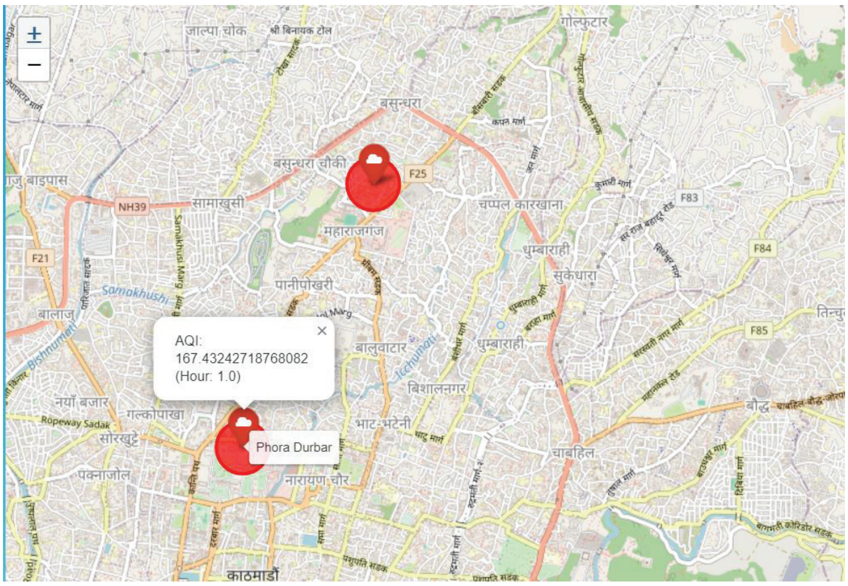

Figure 4: Mapping of AQI for 2 stations (Maharajgunj and Phora Durbar) using Python's Folium library.

Data Visualization

The hourly forecasted value of the AQI has been used to create visualization plots and charts (Figure 5).

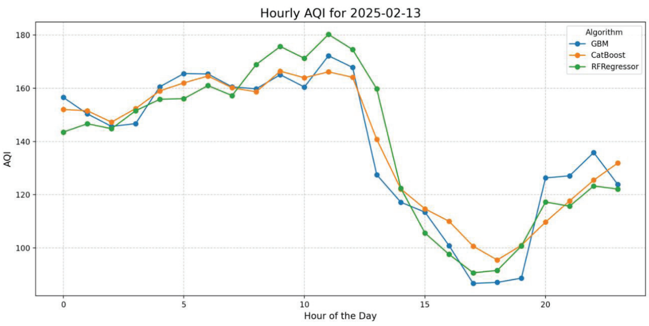

Figure 5: Generated Line Chart (by matplotlib) for a particular day

Conclusion

The proposed web application effectively addresses Kathmandu's air pollution problem by providing real-time AQI monitoring, predictions, and alerts. The system supports public health awareness and environmental monitoring, aligning with Kathmandu Metropolitan City's smart city initiatives. The Random Forest Regressor performed better over the four ML regression-based algorithms with an R^2 of 0.9385, Mean Absolute Error (MAE) of 8.88, and Root Mean Square Error (RMSE) of 13.362. The integration of these predicted values with the intuitive user interface (with the aforementioned functionalities) would serve as a valuable asset for the admin side of the Kathmandu Metropolitan City in terms of effective Air Quality Monitoring and Information dissemination. Future work might include expanding the system to cover more monitoring stations and integrating additional weather data. For larger datasets with a large number of features, Deep Learning and Neural Network alternatives could be considered.

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Status of Sound Pollution and its Impact on Human Health in Dhading Besi

Nisha Adhikari[1], Reeta Singh[2*], Raju Chauhan[2]
[1]Department of Environmental Science, Amrit Science Campus, Tribhuvan University, Nepal,
[2]Department of Environmental Science, Patan Multiple Campus, Lalitpur, Tribhuvan University, Nepal,
Correspondence: reeta.singh@pmc.tu.edu.np, reetasingh80@gmail.com

Abstract

This study focuses on noise status and its impact on human health, in Neelakantha Municipality Ward No. 3 of Dhading Besi. Eleven sites in three different areas were selected as high-traffic, commercial, and residential zones of Dhading Besi. The Sound Level Meter was used to measure with the replicate of five times at each location between 6 am to 7 pm in January 2023 A.D. The health impact of people was assessed among 102 respondents of different categories residing in the study area through a questionnaire-based survey. Result shows that most of the location's average sound level was above the sound level standard prescribed by the Government of Nepal and World Health Organization. From this study, the average sound level of Dhading Besi was measured as 68 dB (A) and that of commercial, high-traffic, and residential areas were 70 dB (A), 72 dB (A), and 63 dB (A) respectively. Average noise was maximum at Puchar bazaar 76 dB (A) in a high-traffic area and the minimum was observed at Ganesh Marg 61 dB (A) in a residential area. In high-traffic areas, the sound level was maximum in the afternoon non-peak hour (12 pm to 1 pm) at 76 dB (A). At all three-area; high-traffic, commercial, and residential area minimum sound level was observed at morning non-peak hour time 66 dB (A), 61 dB (A), and 56 dB (A) respectively. The primary health impacts of noise, as revealed by the questionnaire survey, are headache, irritation, and stress, followed by communication issues, sleep disturbances, and hearing issues. This study serves as a baseline of noise level in the growing suburbs of Dhading and helps to develop the environmental policy for controlling noise pollution.

Keywords: *Equivalent noise, Health impact, High traffic, Noise pollution, Prescribed limit.*

Introduction

Noise is an undesirable sound released into the environment, disturbing human and animal existence (Olayinka, 2012). The word noise comes from the Latin word 'Nausea' which means an unpleasant sound that annoys, and this conveys the same idea that acoustical energy could have negative effects on human health (Singh & Davar, 2004). Noise is defined as 'undesirable sound' and is perceived as an environmental stressor and nuisance. Exposure to continuous noise to 85-90 dB (A), particularly over a lifetime in industry settings, can lead to progressive loss of hearing with an increase in the threshold of hearing sensitivity (Singh & Davar, 2004). Throughout the world, noise pollution has gained global recognition as a significant urban issue, greatly affecting the overall quality of life (Piccolo et al., 2005). A sound above 65 dB (A) can be a noise and a sound above 100 dB (A) can cause hearing loss (Paudel, 2016). The prevalence of excessive noise in the environment leads to the phenomenon of noise pollution. This form of pollution is predominantly attributed to advancements in technology. While industrialization, scientific progress, and technological innovations have undoubtedly contributed to societal development, they have also become primary factors responsible for environmental degradation. Noise pollution, specifically, has emerged as a critical concern affecting the well-being of urban populations across the globe (Ozer et al., 2009).

World Health Organization has prescribed the safe sound level for an urban city as 45 dB (A). In the

United States, a sound level of 65dB (A) at daytime and 55 dB (A) at nighttime in streets is prescribed (Shendell et al., 2009). Anyone crossing the limit is regarded as causing noise pollution. Day by day, noise pollution is on the rise, largely driven by the ever-increasing number of vehicles on the roads. The cacophony on the streets arises from various sources, such as screeching tires, squealing brakes, vehicles reviving their engines, and incessant horn honking. Additionally, the noise emanating from radios, televisions, and music systems adds to the overall urban noise burden, especially when these devices are played at high volumes. Even within homes, modern appliances like washing machines, vacuum cleaners, and mixer grinders contribute to the problem by generating noise pollution. Overall, the combined effect of vehicular noise and various household and entertainment devices has become a concerning issue, negatively impacting the tranquility and quality of life in urban areas Top of ForBotto(Pal & Bhattacharya, 2012).

Noise is sensitive because it may cause hyperacusis which means a hearing disorder. Major sources of noise pollution are traffic noise, construction sites, industry, consort, and restaurants (Wokekoro, 2020). Noise has four different effects on human health and comfort, depending on its volume and duration. Physical, physiological, psychological, and work performance are four major effects caused by sound pollution (Hunashal & Patil, 2012).The International Program on Chemical Safety (WHO, 1999) defines an adverse effect of noise as a change in an organism's morphology and physiology that impairs its ability to function, impairs its ability to compensate for additional stress, or increases an organism's susceptibility to the harmful effects of other environmental influences.

Human activities such as industrialization, urbanization, transportation, and the celebration of a range of holiday activities are the primary causes of noise at the global level (Chauhan & Pande, 2010). Road traffic noise is a major source of noise in urban areas. It produces disturbance and has an impact on more people than any other source of noise. Many researchers have measured sound levels in high-traffic, Campuses, and residential areas. (Murthy et al., 2007) have recorded traffic sound levels in different areas of Kathmandu. During the last one and a half decades, a 70-100 dB (A) range of sound level was observed in urban Kathmandu roads. The level of sound varies in different areas due to variations in traffic flow, crowds of people, and other processes. Mechanical processes like waving, blasting, pressing, drilling, cutting; metal chipping and reverting, etc. can pose a significant occupational health hazard (Joshi et al., 2003).

In addition to better legislation and administration, noise pollution calls for action at the local level. By impairing living, social, working, and learning settings and causing associated real (economic) and intangible (well-being) losses, urban noise pollution has immediate and cumulative negative health impacts. Seven categories of harmful health consequences of noise pollution on people have been identified by the World Health Organization. They are hearing impairments, interference with spoken communication, sleep disturbance, cardiovascular disturbance, disturbance in mental health, impaired task performance and negative social behavior and annoyance reactions. In Nepal's cities, as in other nations, noise pollution is a growing problem that has the potential to be harmful to human health (Chauhan et al., 2021).

In Nepal, most of the noise research focuses on observing noise levels in different areas of Kathmandu. Very few studies have been conducted outside the Kathmandu valley (Pant, 2012) and (Paudel, 2016) have done the research about the Noise pollution in Pokhara valley and Birendranagar municipality respectively, and how they affect locals. However, there are very limited studies in the growing suburbs outside Kathmandu Valley (Neupane & Chauhan, 2024).

To collect the baseline information on the current state of noise pollution and its effect to the inhabitants of ward no. 3 of Neelakantha municipality of Dhading Besi this study has been conducted. Dhading Besi is one of the growing cities as the number of people as well as vehicles movement are increasing. Being a headquarter, it has a variety of facilities *i.e.* education, commerce, job opportunity, transportation services, business, along with the health facility which increase the settlement density, crowd of people, and traffic flow so Dhading Besi was chosen for monitoring ambient noise. Further, study related to noise pollution is lacking in this area hence this study has been conducted with the following objectives (i) examine the current state of noise pollution in Dhading Besi; (ii) compare the levels of noise pollution currently in place; and (iii) investigate the effects of noise pollution on human health.

Materials and Methods

Study sites

The study was conducted in Neelanakatha Municipality Ward No. 03, Dhading Besi (Headquarter of Dhading district) between latitudes 27°50’45.442" to 27°58’1.27" north and between longitudes 84°58’49.98" to 84°56’41.37" east which lies in Bagmati Province of Nepal (Fig. 1). It covers

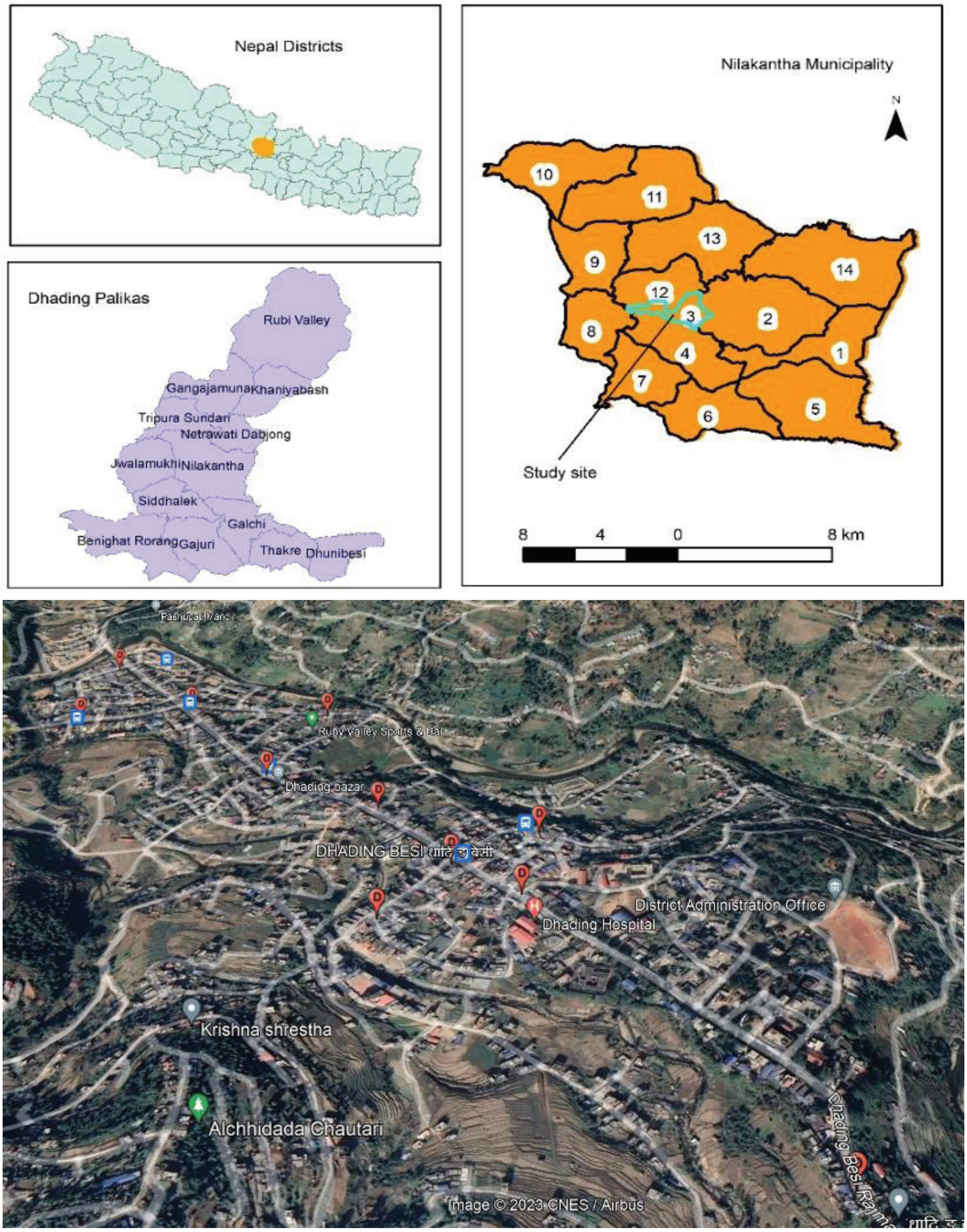

Figure 1: Map showing study site and sampling location

an area of 1926 km^2 and has a population of 12,004 (CBS, 2021).

The sampling sites for noise assessment were selected by first dividing the study area into three zones namely high-traffic, commercial, and residential zones and then selecting at least three sites from each zone. Altogether 11 sites were selected for noise measurement (table 1).

Table 1: Selected sites in different zones for noise level assessment in Dhading Besi

High-traffic	Commercial	Residential
Puchar Bazar	Mulchowk	Ganesh Marg
Bich Bazar	Shanta Bazar	Meelan Tole
Bus Park Chowk	Sugam Tole	Siran Bazar
	Campus Chowk	Tribeni Chowk

Methods

Noise measurement was done from 05/Jan/2023 to 16/Feb/2023 by using the Sound Level Meter of model SL-4012. Measurements were carried out on an A weighting scale in the selected high-traffic, commercial and residential areas at different hours of the normal working days. The sound level meter was placed above 0.5 m shoulder height and a distance of 1.5 m from the road. The sound level was measured for 10 minutes in every 30 seconds and carried 20 readings at each selected location and repeated that process five times a day during morning non-peak hour, morning peak hour, non-peak hour, evening peak hour, and evening non-peak hour) (table 2).The geographical coordinates of the measurement sites were taken using GPS.

Table 2: Time zone distributed for noise assessment

Hour	Time
Morning non-peak hour	6:00 am to 7:00 am
Morning peak hour	9:00 am to 10:00 am
Non-peak hour	12:00 pm to 1 pm
Evening peak hour	3:00 pm to 4:00 pm
Evening non-peak hour	6:00 pm to 7:00 pm

The measurements were carried out under normal atmospheric conditions, having no rainfall and no high wind speed. The maximum noise level (Lmax), the minimum noise level (Lmin), and the equivalent noise level (Leq) were employed as three different types of noise descriptors to evaluate noise pollution. For additional information on human health impact, a questionnaire survey was done among 102 people which was calculated through the sample size formula of Arkin and Colton (1963).

The noise level was measured by using an instrument called a sound level meter (SLM). This is an auto range, the sound level meter of mode SL-4012. It is used in acoustic measurement. The noise level will be measured in decibels (dB (A)). Decibel is used to express different quantities from each other and to measure noise level that gives more weight to the middle or high frequencies that the human ear perceives (Turkekul, 2012). Measurements from 30 to 130 dB (A) can be carried out with this instrument.

2.4 Data analysis

All the data collected were converted to MS Excel and analyzed in average, percentage, graphs, and pie charts. The questionnaire on human health was analyzed in a quantitative manner (graphs, percentages). The Leq was calculated by using the following formula:

$$Leq = 10\log_{10} [1/n\ (10^{L1/10} + 10^{L2/10} + 10^{L3/10} + ...+ 10^{Ln/10})]$$

Where $L_{1,} L_{2,} L_{3, ...,}$ Ln are the equivalent noise level readings given by the sound level reading at each interval, and n is the number of recordings for the given duration of time. Other descriptors, such as Lmax, Lmin were also computed.

Results and Discussion

Status of Noise level in Dhading Besi

The overall status of noise level in all the studied zones of Dhading Besi has been presented in Fig .2 below. Among 11 locations, the average noise level was highest in Puchar Bazar (75 dB (A)) and lowest at Ganesh Marg (59 dB (A)).

The average noise level ranged from 68 dB (A) to 75 dB (A) in high-traffic, 59 dB (A) to 65 dB (A) in residential and 69 dB (A) to 71 dB (A) in commercial zone as depicted in Fig. 2. The maximum (Lmax), minimum (Lmin) and average noise level for the three zones followed the order high traffic areas > commercial areas > residential areas. The average sound was measured as 72 dB (A), 70 dB (A), and 63.6 dB (A) in high-traffic, commercial, and residential zones, respectively. A similar pattern of noise was recorded by Chauhan and Bhatta (2019) and Chauhan et al. (2021). The maximum equivalent sound level was measured as 85.23 dB(A), whereas the minimum sound level was observed as 77.81 dB(A) in different wards of Kathmandu metropolitan city (Maharjan et al., 2021). Similarly, studies at different locations of Kathmandu inside the Ring Road, maximum noise (Lmax) was observed as 101.7 dB (A) at Chabahil while minimum was observed as 48.1 dB (A) to 68.0 dB (A) which could be due to the free flow of vehicles (Singh et al., 2022). Also, in Ahvaz city of Iran maximum sound level was observed to be 95.46 dB (A) and the minimum sound level as 57.25 dB (A) (Geravandi et al*.,* 2015). The authors have mentioned that Ahvaz city faced an increasing sound level due to the load of traffic flow. In general, the environment of the surroundings, the distance to the source, the density of the source's flow, and the types and circumstances of the sources affect the degree of noise.

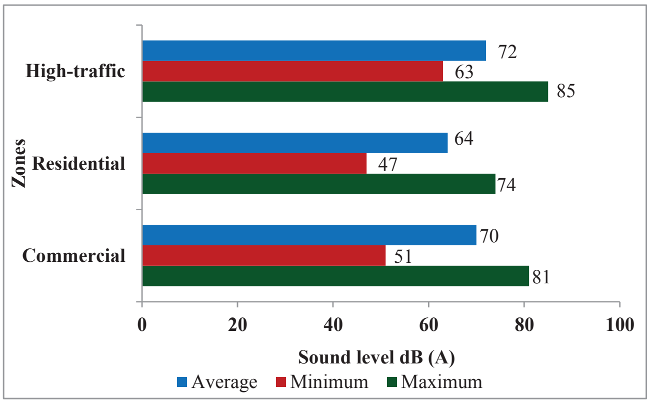

Figure 2: Minimum, maximum, and average noise level in three different zones

The average traffic noise in Dhading Besi was found to be 68 dB (A) among three different selected zones. Different studies have also reported average sound levels of Kathmandu metropolitan city as 76.3 dB (A) and 82.5 dB (A) respectively (Maharjan et al., 2021; Singh et al., 2022). However, the average noise level was marginally below 72.25 dB (A) in the city of India, Kolphur (Hunashal & Patil, 2012). They mentioned the rise in noise level was due to rapid population growth, business activities and industrialization. Similarly, during the daytime, the noise standard in major road arteries in Bangkok was observed as 79.2 dB (A), and in Minnesota as 70 dB (A) (Kudesia & Tiwari, 2007). The WHO (1999) recommends a guideline value of 55 dB (A) for noise in residential, institutional, and educational settings and 70 dB (A) for industrial, commercial shopping, and transportation sectors during the day (WHO, 1999).The National Ambient Sound Quality Standard of Nepal, (NASQS) 2012 states that during the daytime, the allowed noise levels are 55 dB (A) for residential areas and 65 dB (A) for commercial sectors. Thus, the present sound level in Dhading Besi was found to be above the permissible level of national and international standards.

Status of Noise Level in Commercial Areas

The status of the sound level measured in the commercial area is presented in Fig. 3 below. It indicates that among the commercial areas, Shanta Bazaar had the highest sound level of 71 dB (A), higher than the standard given by NASQS. This might be because of various activities such as business, restaurants, and shops. These areas are often bustling with people, vehicles, loud music, plus machinery work, which contributes to overall noise levels. Additionally, in this area, the movement of vehicles was found in large numbers for the delivery of goods. Mul Chowk and Sugam Tole have the same sound level of 70 dB (A) because all those locations have a high number of automobiles and people, also traffic management systems were also managed. Both locations are equal with the sound level prescribed by WHO. However, at Campus Chowk the lowest sound level was measured as 69 dB (A), among commercials, which might be because of the hospital area and the nearby high school. This sound level in this area meets the standard prescribed by WHO but it exceeds the national standard prescribed limit. In Mul chowk, the bazar area management was quite good. Finally, at Sugam tole 70 dB (A) noise level was observed, may be due to lower number of vehicles as well as slight movement of people.

The different zones, like high traffic, commercial, and residential areas, have been differentiated according to the land use type (Chauhan et al., 2021). The commercial area can be related to the busy area. The Commercial area had experienced a heavy crowd of people as well as more engagement of automobiles. Similarly, low levels of noise in the residential area are due to lower vehicle pressure than in other main roadside areas and lower crowds of people. These results suggest that the main sources of noise in Dhading Besi are automobiles, traffic, vehicular increment, and crowds of people. The various sound levels are also noticed at various times during the day. In commercial areas, sound levels are reported at their highest during the day (between 12 pm to 4 pm) i.e., 74 dB (A), and lowest at their morning non-peak hours (between 6 am to 7 am).This may be because of large number of people who live in these areas spend much of their daytime hours buying and selling items to support themselves.

The results show that at each location the average noise level at commercial zones comply with the international standard (WHO, 2018) but when compared to NASQS standard, four mentioned sites were above the prescribed standard. At Buspark Chowk maximum equivalent sound level of 70.01 dB (A) and the minimum equivalent sound level of 67.3 dB (A) was measured in Basnet chowk of the commercial area of Birendranagar municipality due to the busy traffic routes and also increasing number of buses, jeep with the crowded of people (Paudel, 2016). Also (Pant, 2012) measured 60 dB (A) of equivalent sound level at a day time in the commercial area of Pokhara Sub-Metropolitan city due to the number of road vehicles, pressing horns, and old vehicles, besides these loud speaker is also the source in this city.

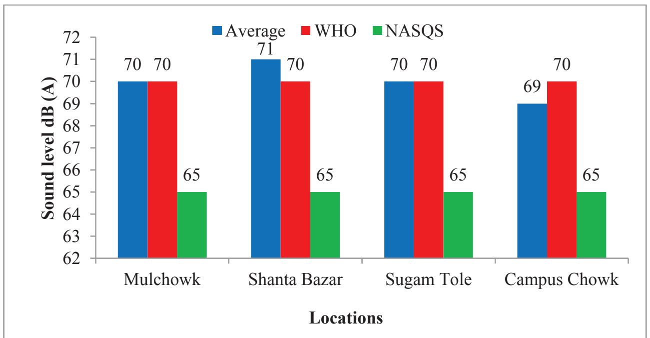

Figure 3: *C*omparison of sound level within the commercial area

Status of Noise Level in high-traffic areas

The average sound level inside the high-traffic region has been presented in Fig. 4 below. The highest noise level was observed at Puchar Bazar, i.e., 75 dB (A), which exceeded the WHO standard. Similarly, Bich Bazaar and Bus Park Chowk have sound pressure levels of 74 dB (A) and 68 dB (A), respectively. Due to their similar characteristics of traffic flow and population density, the two places, except Bus Park Chowk, have a slightly varied degree of sound, which is shown in Fig. 5.

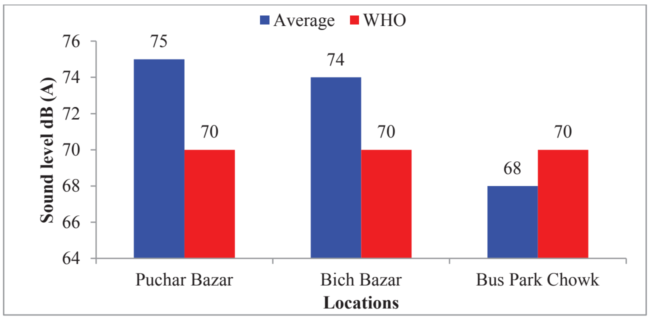

Figure 4: *Comparison of sound level within high traffic*

Due to the dense population, crowded environment, and high traffic flow, the high-traffic area experiences the highest sound intensity. Additionally, some automobile pressure horns also increase the noise level in this region. Similarly, in high-traffic areas, sound levels are reported to be highest in afternoon hours (between 12 pm to 1 pm) i.e., 76 dB (A), and lowest in morning non-peak hours (between 6 am to 7 am) i.e., 66 dB (A). The maximum sound level in the afternoon time might be due to maximum vehicle pressure, traffic flow in huge numbers, crowds of people, and unmanaged parking of automobiles to load the goods and passengers. The low level of sound was recorded in the morning hours, which may be because of less movement of vehicles and less mobility of people at that time.

There is variation in traffic noise standards in different countries so in Nepal. In Nepal, traffic noise standards have mentioned permissible level of 70 dB (A) (Sapkota, 1997). In the present, study it was found that variations in traffic sound levels in Dhading Besi might be due to the plying or more vehicles on the roads, using loudspeakers and unmanaged traffic system where average noise level exceeded the standard level (WHO, 2018) in all sites. According to research done by (Sapkota, 1997; Singh et al., 2022) noise levels in Kathmandu's high-traffic areas ranged from 65.1dB (A) to 74.5 dB (A) and 78.97 dB (A), respectively, which is due to the maximum number of vehicles. The average equivalent sound level of Kathmandu valley was calculated by (Chauhan et al., 2021) in which high traffic area was measured 73.2 dB (A).

Status of Noise Level in Residential Areas

The typical noise level in residential zones is presented in Fig. 5. Among the four locations of residential zone, Tribeni Chowk has the highest sound level, at a maximum of 65 dB (A), followed by Siran Bazar i.e., 64 dB (A), Ganesh Marg i.e, 59 dB (A), and Meelan Tole i.e, 64 dB (A). All these sites cross the standard of WHO and NASQS (annex I). Each of these four areas has a very similar sound level status which might be because of the similar mobility of people and similar population density.

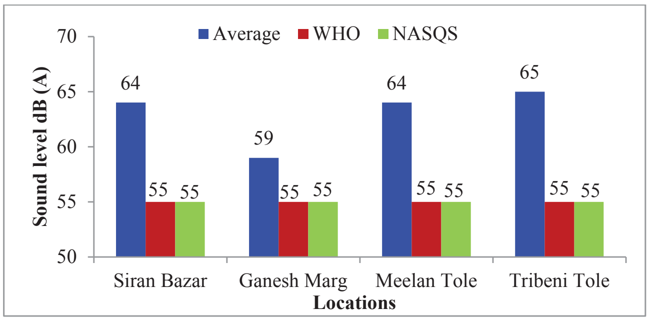

Figure 5: Comparison of sound level within residential areas

Due to the low vehicular movement and less population density residential areas might have low sound levels in comparison to other zones, Although the sound level in a commercial area is much higher than in a residential area but slightly lower than in a high-traffic area. The residential area is comparatively silent in comparison with other zones, like high-traffic areas and commercial areas. But at all the residential zones prescribed standard of noise level were above the standard of WHO and NASQS. According to (Chauhan et al., 2021) and (Singh et al., 2022) average sound level at residential areas of Kathmandu was measured 56.8 dB (A) and 74.52 dB (A), respectively. The average sound level was measured 58.9 dB (A) in Kolhapur city, Maharashtra, India (Mangalekar et al., 2012) and mentioned that transportation was the main cause of the increasing sound.

Temporal pattern of noise in Dhading Besi

The noise level measurement was done at five different hours i.e., Morning non-peak hour, morning peak hour, non-peak hour, evening peak hour and evening non-peak hour. It is evident from Fig. 6, that the temporal noise patterns are observed to be similar at the morning peak hour (9:00 am-10:00 am), non-peak hour (12: 00 pm- 1:00 pm), and evening- peak hour (3:00 pm-4:00 pm) which is also the highest sound level i.e. 71 dB (A). This might be because of the same flow of automobiles, unmanaged traffic, people and unmanaged parking system. At this time, traffic flow was high because of the high number of vehicles from the upper area of Dhading Besi who are engaged to drop people and take back the goods that are needed for their daily use. And the lowest during morning non-peak hour (6:00am-7:00am). However, the intensity of sound in the evening non-peak hour (6:00 pm- 7:00 pm) is also higher than in the morning non-peak hours, which may be due to extremely loud noise of vehicles and maximum people engagement for the grocery in the Puchar Bazar area. Puchar Bazar also consists of petroleum stations of automobiles.

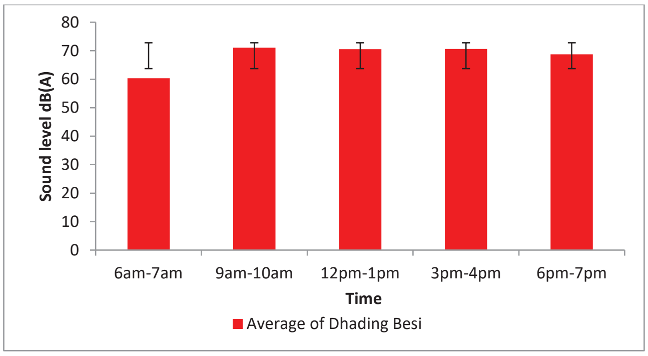

Figure 6: Overall temporal pattern of noise in Dhading Besi

Five separate times, namely morning non-peak, morning peak, non-peak, evening peak, and evening non-peak, were used to measure the noise level at different zones like high traffic, residential and commercial zones. Fig. 7 depicts three kinds of noise pattern which includes the highest noise level during non-peak hour (commercial and high-traffic) and morning peak-hour (residential), and the lowest noise level was during morning non-peak hour (commercial, residential and high-traffic). The average noise level during morning non-peak hour, morning-peak hour, non-peak hour, evening-peak hour, and evening non-peak hour were 61 dB (A), 71 dB (A), 71 dB (A), 71 dB (A), and 69 dB (A) respectively. The main cause of noise pollution was due to an increase in the number of automobiles, traffic flow, loudspeakers as well as vehicles.

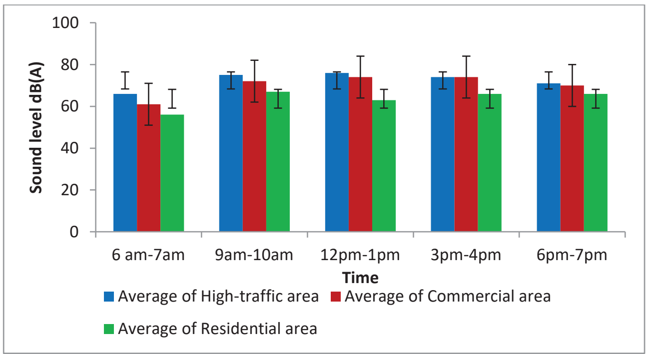

Figure 7: Temporal pattern of noise level in different zones

Effects on human health due to noise pollution

The effects of noise pollution on human health have been depicted in Fig. 8 below. The figure reveals that majority of respondents are affected by noise from traffic flow. Most respondents, 44% across all age groups, believe that the noise from automobiles has the biggest impact on their daily activities. Similarly, 20% of respondents across all age groups agree that loudspeaker noise has a great negative impact. Nearly 20% of respondents are affected by the noise of loudspeakers. Also, 12% of respondents claim that they are affected by the noise produced by the neighborhood, 10% by parties, 6% by industrial machinery, and 8% by commercial construction.

According to the survey, loudspeakers, neighborhood activities, parties, industrial machinery, and

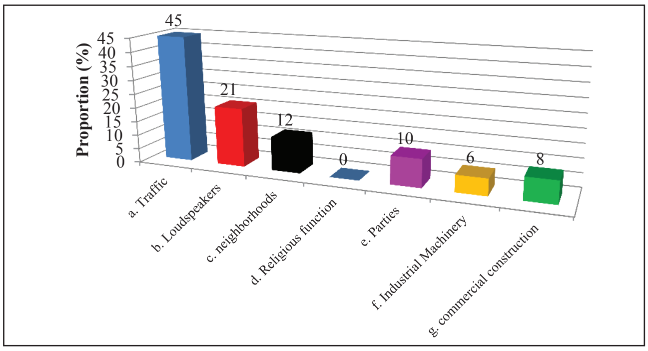

Figure 8: Major noise sources based on the perception of the respondent

commercial construction are also significant sources of noise pollution. Besides this, automobiles and traffic flow are the main causes of noise pollution.

The general health effects of noise pollution based on the perception of respondents is presented in Fig. 9 below. Among the various health effects, irritation is felt by a slightly higher percentage i.e. 27% of respondents followed by headaches (21%), stress (22%), loss of sleep (10%), and 10% reported to be affected by hypertension, respectively. Also, this survey has reported that 10% of respondents felt no disturbance. This survey results revealed that the overall impact of noise varies depending on the age group. More respondents faced irritation due to the loud noise. According to (Geravandi et al., 2015), the primary health impacts of the noise were anxiety, poor sleep, hypertension, hearing loss, mental health issues, depression, and myocardial infarction in the Ahvaz City of Iran. Due to noise exposure, millions of Americans have heart disease and hearing loss, among other detrimental health effects (Hammer et al., 2014).

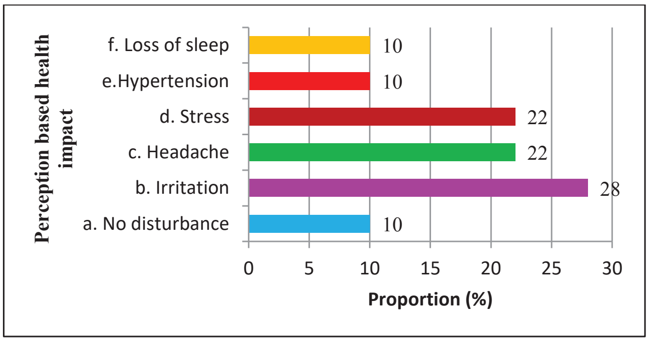

Figure 9: Health impact of noise as reflected by the perception of the respondents

Suggestion for Noise reduction by the respondents

The individual reactions to a set of potential solutions for noise predicted as suggested by responded have been shown in Fig. 10 below. The results show many respondents are worried about government commencement, education, and technological advancements. Monitoring noise levels could be undertaken by the environment section of the Nilakantha Municipality and empowering NGOs. Also, some of them believe that empowering police can reduce the noise level on some level.

But we know that a single measure can't help to reduce the noise level. Hence, strengthening the capacity of the local authorities for environmental pollution monitoring appears to be the best method as suggested by respondents. Also, education and awareness are the key points and the most efficient approach to eliminating noise. Through education, the flow of information about noise pollution among people could be effective as many people are unaware of environmental rules and regulations. They also mentioned that government efforts could help to reduce the increasing level of noise in the study area.

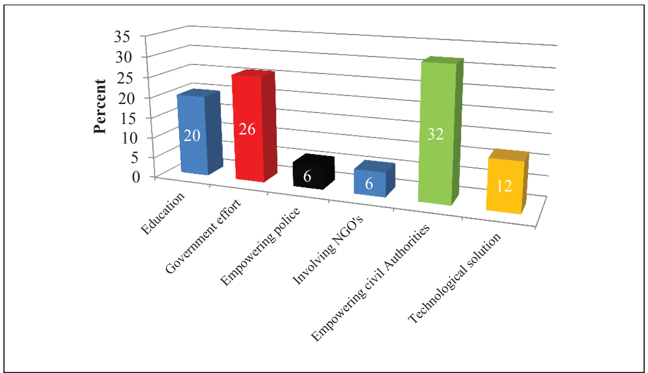

Figure 10 : Measures for controlling noise pollution as suggested by the respondents

Conclusion and Recommendations

The average level of sound in Dhading Besi was found to be 68 dB (A). Similarly at Commercial, High-traffic, and Residential area it was found to be 70 dB (A), 72 dB (A), and 63 dB (A) respectively. The sound level was exceeded according to the government of Nepal as well as the international standard of WHO guidelines. Maximum sound level was found at High-traffic area i.e., Puchar Bazaar of 86 dB (A) and the minimum was found at Residential area i.e., Ganesh Marg of 43 dB (A). The questionnaire survey reveals that improper communication, annoyance, and hearing problems were felt by most of the respondents. The survey identified traffic, and loudspeakers are the major sources of noise pollution. Empowering civil authorities would be the best method as suggested by respondents. Besides this government effort, education, and technological solutions can also play a significant role in the process of controlling excessive noise.

To reduce the noise pollution level and prevent the major effects on human health in the study area and other places, the following recommendations are suggested.

- Promoting public education and awareness about the impacts of noise pollution can encourage individuals to make conscious efforts to reduce their noise emissions.
- Since the transportation system is thought to be the main cause of noise pollution, technical plans like road maintenance, expansion of roads, repairing of engines, repairing of bad condition of vehicles, and limiting the speed of vehicles, etc. should be implemented.
- Tree planting and vegetation should be adopted along the roadside as a barrier to control noise.

Annex1: National Ambient Sound Quality Standard, 2012

S.N.	Areas	Noise level dB (A)	
		Day time	Nighttime
1	Industrial Area	75	70
2	Commercial Area	65	55
3	Rural Residential Area	45	40
4	Urban Residential Area	55	45
5	Mixes Residential Area	63	55
6	Peace Area	50	40

Source: CBS, 2019 (Ministry of Environment, Science and Technology, Nepal Gazette 2069/07/13).

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Potability of Bottled and Jar Water in Kathmandu Valley: A Comparative Analysis

Binit Timalsina[1, 2], Kishor Kumar Maharjan[1*], Anjal Mahat[1], Prakash Chandra Wagle[1], Praveen Kumar Regmi[1], Hira Bahadur Karki[1,3]

[1]Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal
[2]Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal
[3]College of Applied Science, Tribhuvan University, Kathmandu, Nepal
[*]Correspondence: env.kishor@gmail.com

Abstract

Access to safe and clean drinking water is recognized as a fundamental human right. Kathmandu faces a number of problems in drinking water distribution, packaging and its availability. Human right assures for safe drinking water for healthy and prosperous life. This research aimed to compare drinking water quality of bottled and jar water in Kathmandu Valley on which most people are dependent on. 15 samples of each bottled water and jar water were collected from Kathmandu Valley. Both the physico-chemical and bacteriological parameters were analyzed. The physico-chemical parameters of bottled and jar water were compared statistically. Weighted arithmetic water quality index (WQI) method was used to oversee the quality of the water samples providing weightage to each parameter based on their standard value provided by National Drinking Water Quality Standards (NDWQS). Seven samples from bottled water and three samples from jar water had iron concentration greater than the maximum permissible limit set by NDWQS. Similarly, five samples from bottled water had pH value less than 6.5. Most Probable Number (MPN) test indicated all samples to be free from microbial contamination. There were significant differences between bottled water and jar water in terms of temperature, pH, ammonia, phosphate and iron ($p<0.05$). Among the measured parameters, pH, iron, and ammonia were found to be key contributors influencing the WQI, highlighting their value deviation from standard value. Majority of the samples from bottled water did not comply with the standards with respect to pH and iron concentration. The WQI assessment and bacteriological test indicated that all sampled waters were of good quality for drinking purposes. However, regular monitoring is recommended to ensure the continued safety and quality of drinking water in Kathmandu.

Keywords: *Drinking Water, MPN Test, Suitability, Weighted arithmetic, WQI*

Introduction

Water is found everywhere and in different forms but only 2.5% is freshwater, the water that we are directly connected with (Chen et al., 2022). The actual amount of total renewable water resources in south east Asia was almost 11,632 m^3 per person per year in 2012 (Pandey & Shrestha, 2016). Only 18% of the total population in 2020 uses safely managed drinking-water services in Nepal, whereas 74% of the global population uses safely managed drinking water (UN-Water, 2021). In Kathmandu Valley, the average water production of Kathmandu Upathyaka Khanepani Limited (KUKL) is only 300.02 million litres per day (MLD), while the demand is 506 MLD (KUKL, 2023). The remaining demand is fulfilled by either unprocessed water like well, tube well and boring or by processed water like jar water and bottled water. Due to the lack of fulfillment of drinking water supply in Kathmandu Valley, demand of jar water is accelerating (Kharel, 2019). Out of 550 bottling plants in Nepal, 150 water bottling plants are based in Kathmandu Valley. Private water bottling plants fulfill almost 75% of water demand (Prasain, 2020). Due to the easy availability and accessibility of purified water, bottled water has gained popularity in the market (Rai et al., 2015). This has led to increasing bottled water consumption at sharp rates in Nepal alike all over the world (Fiket et al., 2007 & Rai et al., 2015).

Timilshina et al. (2013) revealed that in response to the increasing demand and consumption of bottled water in the Kathmandu Valley, concerns have been raised over water quality. In this study, conducted approximately a decade ago, revealed 90% of bottled water samples exceeded the acceptable limits for heterotrophic bacterial counts. Rai et al. (2015) reported 62.5% of samples of bottled water had heterotrophic count above acceptable range (<50 CFU/0.1 mL) and 75% crossed World Health Organization (WHO) guidelines (0 CFU/0.1 mL) and *Escherichia coli* was observed in 13 samples out of 25 analyzed samples in eastern Nepal. In contrast, Neupane et al. (2019) analyzed the quality of sealed bottled water of different brands with Nepal's Drinking Water Quality Standard (NDWQS) in Bhaktapur, and it was found that none of the samples was microbiologically contaminated; however, 69% of the samples did not comply with the standard pH limit.

Kambalagere & Puttaiah (2008) used a method where all the water quality parameters were provided individual weightage, that results to the single index indicating the water quality status. The method categorized the index value into 5 categories from 0-25, 25-50, 50-75, 75-100 and >100 resembling excellent, good, poor, very poor and unsuitable for drinking water, respectively. In this study, 'jar water' meant a 20-litre bottle of water and 'bottled water' meant a one-litre bottle of water that are commercially produced by water processing and filtering companies. These companies claim bottled water to be safe for drinking purpose. Therefore, this study aimed to compare the quality of bottled water and jar water in Kathmandu Valley (Kathmandu, Bhaktapur and Lalitpur districts). The results were also compared with the National Drinking Water Quality Standard (NDWQS), 2022 and WHO Guidelines.

Materials and Methods

Study Area

Kathmandu Valley, situated in central Nepal, is a tectonic basin surrounded by the green hills, with an average elevation of approximately 1,300 meters above sea level. The valley lies within the extent of 27°32'13" and 27°49'10" N latitudes and 85°11'31" and 85°31'38" E longitudes. It serves as the political, economic, and cultural hub of Nepal and encompasses three historically significant cities:

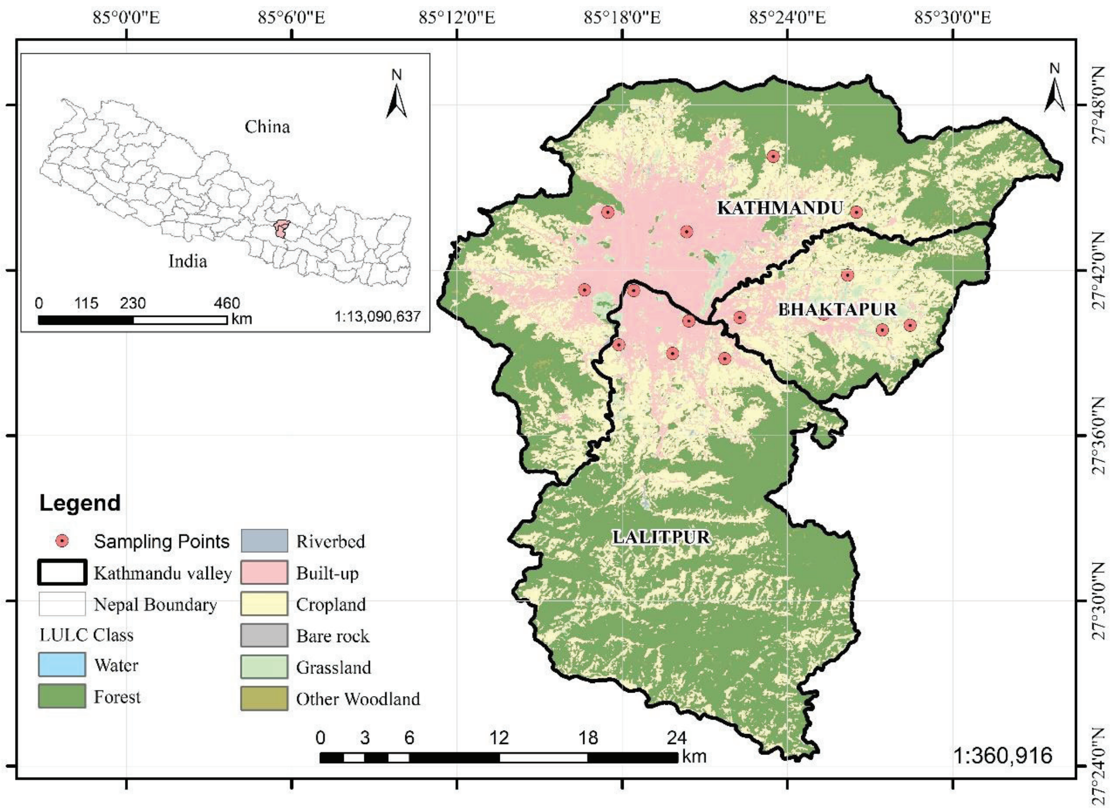

Figure 1: Sampling area in Kathmandu Valley including Kathmandu, Bhaktapur and Lalitpur districts

Kathmandu, Lalitpur, and Bhaktapur (Pandey et al., 2023). It covers a total of about 899 km^2 area and population of 3,025,386 (NSO, 2024). The major sources of drinking water in the valley are tap water, dug wells, shallow tube wells, deep tube wells, stone spouts (*dhunge dharas*), tanker truck water and processed water. These water are also used for domestic purposes (Sarkar et al., 2022). The valley is renowned for its rich cultural heritage, featuring several UNESCO World Heritage Sites that reflect the deep influence of Hindu and Buddhist traditions. Rapid urbanization has led to challenges such as environmental degradation, air pollution, and water resource depletion. Despite these pressures, the valley remains a center for academic research, tourism, and cultural preservation. The valley is traversed by the Bagmati River by mixing of various rivers such as Bishnumati, Manohara, Tukucha, Nakkhu, etc.

Sampling Design and Methodology

The drinking bottled and jar water samples were collected from the districts of Kathmandu Valley i.e. Kathmandu, Bhaktapur and Lalitpur from various shops, hotels, hospitals and shopping malls. The sampling was carried out by using stratified random sampling method in which a total of 30 drinking water samples were collected from the valley. It includes 15 bottled water and 15 jar water of different brands, five-five from each district. Sample collection was carried out in the month of December (Winter Season), 2020. Bottled water and jar water registered in Department of Industry under the Ministry of Industry, Commerce, and Supplies were only used. The samples collected were tested in the laboratory of Environmental Department of Tri-chandra Multiple Campus, Ghantaghar.

The temperature, pH, TDS, Electrical Conductivity were measured at the field. Later, the samples were stored in the ice cooled bag at very low temperature and other physicochemical and microbiological test were done within 48 hours of collection. The sampling bottle for collection of jar water were sterilized in the autoclave at 121°C for 15 minutes. The physical, chemical and microbiological quality of drinking water samples were examined as per the methods (Table 1) described in APHA (2017). Weighted arithmetic water quality index (WQI) method classified the water quality based on the purity level of parameters measured. It is calculated using the equation (i).

$$WQI=\frac{\Sigma q_i W_i}{\Sigma W_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(i)$$

(Tyagi, Sharma, Singh, & Dobhal, 2013)

Where q_i is the quality rating scale and W_i is the unit weight of the i^{th} water quality parameter.

Data Analysis

The data were collected and stored in MS Excel 2013. The data thus obtained were compared with

Table 1: Tested parameters, methods and the instruments used for analysis

S.N.	Parameters	Methods	Instruments
1	Temperature (°C)	Thermometric	Thermometer
2	pH	Potentiometric	pH Meter
3	Electrical Conductivity (µS/cm)	Conductivity	EC 59 Milwaukee
4	Total Dissolved Solids (ppm)	TDS meter	EC 59 Milwaukee
5	Iron (mg/L)	Spectrophotometric (Phenonthroline method)	LI-285 Microprocessor UV-VIS Single Beam Spectrophotometer
6	Calcium Hardness (mg/L)	EDTA method	Glassware (Titration)
7	Total Hardness (mg/L as $CaCO_3$)	EDTA method	Glassware (Titration)
8	Chloride (mg/L)	Argentometric Titration method	Glassware (Titration)
9	Phosphate (mg/L)	Spectrophotometric (Stannous Chloride)	LI-285 Microprocessor UV-VIS Single Beam Spectrophotometer
10	Ammonia (mg/L)	Spectrophotometric (Phenate method)	LI-285 Microprocessor UV-VIS Single Beam Spectrophotometer
11	Total Coliform & Fecal Coliform (Cfu/100 mL)	MPN method	Test tubes, Autoclave, etc.

the WHO (2017) guidelines and NDWQS (2022). Also, the result of water quality parameters of bottled water and jar water were also compared with each other. Statistical analysis was carried out using Rstudio version 4.3.1 (R Core Team, 2023). The normality of the data was tested by Shapiro-wilk test. So, Student's t-test were applied where the p-value > 0.05 from Shapiro-wilk test and remaining were dealt with Mann-Whitney U test (p-value < 0.05). The level of significance for the statistical test was considered to be 5% (0.05).

Results and Discussion

The comparative analysis of bottled and jar water samples was carried out where physical and chemical parameters were analyzed along with total coliform and *E. coli* as biological parameters.

The analysis during the study showed that the temperature of bottled water was in the range of 9.2°C to 12°C whereas 11.8°C to 12.9°C for jar water. Temperature of samples were measured during the time of collection and they were stored in the room temperature at the site of sample collection. The optimum temperature required for water is 25°C. The reason behind low temperature of water samples might be the low temperature of surrounding as the sample collection was carried out during winter season based on heat transfer equation (Malasri et al., 2015). Though there is no direct effect of temperature over the drinking water, there is no such variations in temperature of bottled and jar water. The pH value for neutral water is 7.5 at 0°C, 7 at 25°C and 6.5 at 60°C (APHA, 2017). Thus, temperature plays the key role in determining pH and change in water temperature effects the other water parameters such as TDS, EC as well as the microbial growth and development. Although the temperature of bottled and jar water was within the optimum temperature range, there is a significant difference between their temperature.

The high concentration of TDS was observed as 47 mg/L in bottled water and 125 mg/L in Jar water whereas the lowest concentration was 6 mg/L in bottled and 8 mg/L in jar water. All the water samples including both bottled water and jar water lie within the maximum permissible limit given by NDWQS making the water suitable for drinking. The TDS value below 300 mg/L is regarded as the excellent quality in terms of palatability of Drinking Water. Thus, all the water samples can be regarded as excellent in terms of palatability as their value lie below 300 mg/L (Fig. 2). However, the TDS means all sorts of ions dissolved in water including nitrates, arsenic, copper, iron, etc. which may possess the health risks also.

Similarly, there was a no significant difference between the TDS in the bottled water and the jar water. Statistically, we can say that the total dissolved solids in the bottled water and jar water are almost same. Hence, both sample water has no quality difference.

The highest value of electrical conductivity was observed as 93 µS/cm for jar water and 249 µS/cm for bottled water whereas lowest value was 12 µS/cm for bottled water and 16 µS/cm for jar water. The maximum permissible limit is 1500µS/cm given by WHO and NDWQS, and all the samples lie within the standard limit. As temperature, EC also has no direct influence on drinking water quality but it is an indicator of TDS. According to Selvaraj & Joseph (2009), the ratio of TDS to EC always lies within the range of 0.55 to 0.7.

The pH value of bottled water was in the range of 6-6.9 and the jar water were in the range of 6.8 - 7.9. According to the standard set by NDWQS, the range for pH for drinking water is 6.5 to 8.5. Hence, five samples of bottled water were below the acceptable limit. Neupane et al. (2019) & Maskey et al. (2020) also analyzed the bottled water quality of Bhaktapur and Pokhara valley respectively which found most of the sample water slightly acidic in nature. According to WHO, health effects are most pronounced in pH extremes. The pH below 4 can cause irritation and worsen existing skin conditions due to its corrosive effects whereas pH above 11 can causes skin, eye and mucous membrane irritation (WHO, 2017). pH value above 8 makes chlorine disinfection less effective. Both bottled water and jar water are treated with chlorine for disinfection and the effectiveness of chlorine will get reduced if pH is greater than 8. Likewise, the p-value ($p < 0.05$) shows that the bottled water and jar water have significant difference between their pH values.

The concentration of chloride in bottled water was in the range of 8.52 mg/L to 14.06 mg/L whereas jar water was in the range of 2.84 mg/L to 19.88 mg/L. The maximum permissible limit for chloride is set as 250 mg/L as per WHO guidelines and NDWQS, and all the water samples are within the acceptable range which shows the suitability for drinking purpose. In fact, the water samples contain relatively low concentration of chloride. Low to moderate concentration of chloride in the drinking water adds palatability in drinking water, however, excess concentration makes water unpleasant for drinking. Statistical analysis shows that the chloride in jar and bottled water have no any significant difference and ensure the sound quality.

Hard water requiring considerably more soap to produce a lather. Packaged water can exhibit diverse characteristics, including being naturally rich in minerals, naturally soft, or demineralized (WHO, 2017). The concentration of calcium was in the range of 2 mg/L to 26mg/L for bottled water and the range of 4 mg/L to 60 mg/L for jar water. The maximum permissible limit for calcium is 200 mg/L according to NDWQS. Its value is very low as compared to the standard. Higher the content of calcium in water, harder the water and higher hardness increases the unsuitability for drinking purpose. The total hardness of water is the measure of calcium and magnesium as $CaCO_3$ and $MgCO_3$. The total hardness of the ranges from 6 mg/L to 30 mg/L for bottled water and 6 mg/L to 50 mg/L for jar water. The maximum permissible limit for drinking water is 500 mg/L. Thus, all the water samples are safe for drinking. The p-value from the t-test shows that there is no significant difference between the jar and bottled water in terms of calcium hardness and total hardness.

Iron in water is present in both ferric and ferrous form. The iron content in bottled water ranges from 0.09 mg/L to 0.60 mg/L and from 0.01 mg/L to 0.32 mg/L for jar water. Seven water samples from bottled water and two water samples from jar water contained iron greater than the permissible limit set by WHO guidelines and NDWQS i.e., 0.3 mg/L. There is significant difference between the quality of jar water and bottled water with respect to the availability of iron in the water ($p < 0.05$). In addition, in the current research done by Burlakoti et al. (2020), the iron level on some jar water in Kathmandu Valley were above the permissible level however the average level was below 0.3mg/L. NDWQS (2022) clearly state that the iron concentration gets objectionable if it crosses the limit of 3 mg/L.

The concentration limit for ammonia in drinking water is 1.5 mg/L as set by NDWQS. The value above 1.5 is unacceptable and regarded as unsafe for drinking. The ammonia concentration in bottled water ranged from 0.007 mg/L to 1.188 mg/L and from 0 mg/L to 0.22 mg/L in jar water. All the samples fall within the standard set by NDWQS. Skin corrosions, eye irritation, respiratory tract irritation, etc. are the probable health effects if ammonia concentration is higher. Statistically, there is a significant difference between the jar and bottled water ($p < 0.05$). In the study carried by Burlakoti et al. (2020), we can find the 48% of jar water samples had ammonia content greater than the permissible limit. It is also an indicator of water contamination, primarily due to sewage and animal waste (WHO, 2017).

The phosphate in drinking water is not provided in the NDWQS but it ranges from 0.003-0.08 mg/L in jar water and 0.03-0.10 mg/L in mineral-bottled water. Phosphate with its low concentration can affect the growth of algae in water (Yaakob et al., 2021). The t-test shows that there is a significant difference in jar and mineral-bottled water ($p < 0.05$).

Microbial test for water before packaging is indispensable (Joseph et al., 2018). According to NDWQS, the *E. coli* should be in 100% samples and total coliform should be 0 in 95% samples. However, all the water samples were carried out for MPN test and none of the samples showed positive result. Even in the confirmatory test, colonies were not formed after incubation in the agar solution. Both the bottled water and jar water were *E. coli* and total coliform free. This microbial test shows that both water samples were contamination free and safe for drinking.

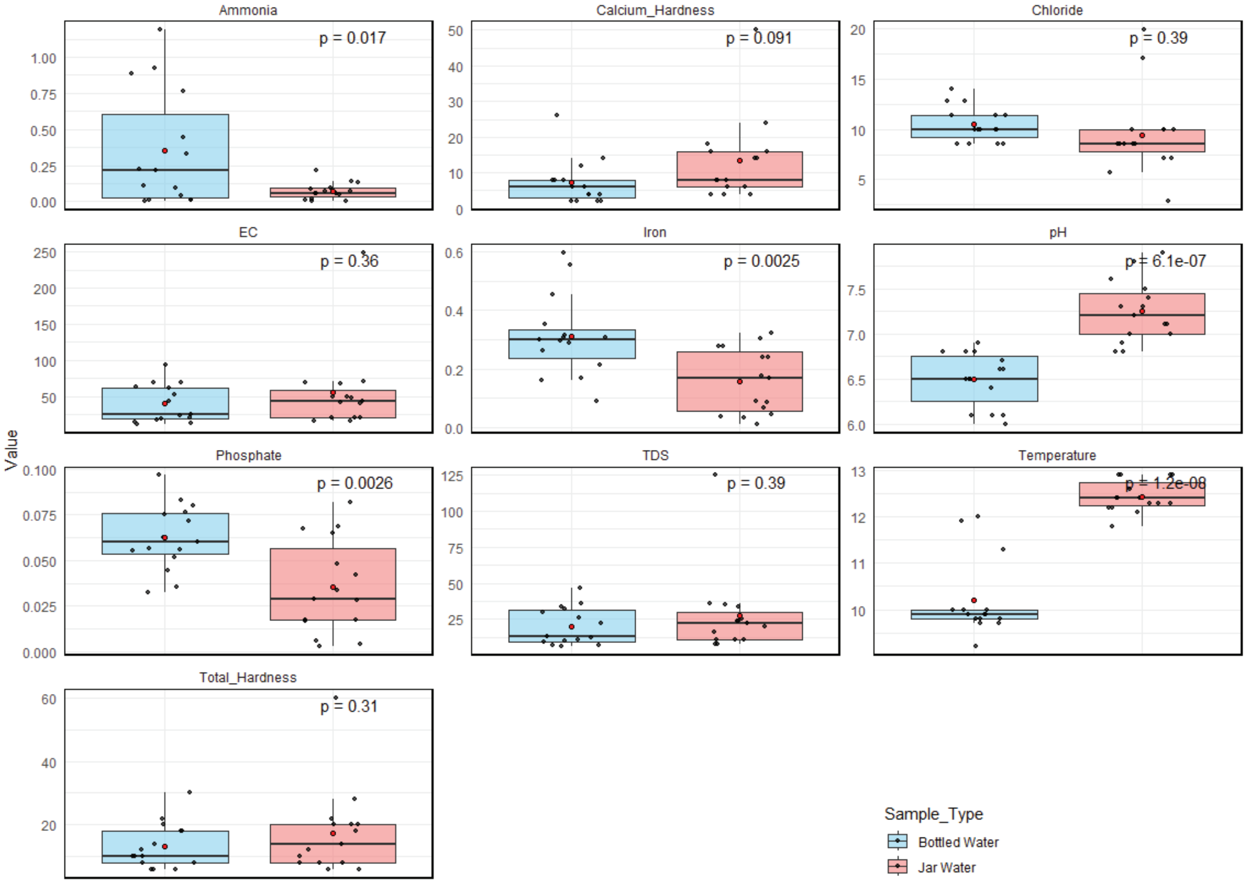

Figure 2: Comparison of physico-chemical parameters of both jar and bottled water

The study done by Neupane et al. (2019) and Yousefi et al. (2018) are comparable to the result of our analysis. None of the water samples were contaminated in those study also which were carried out at Bhaktapur and Sari (Iran) in bottled water respectively. Despite the result, the study carried by Maharjan et.al (2019) revealed that 92% of jar water were contaminated with Coliform bacteria. For a detailed investigation and comparison of water quality, it is necessary to conduct similar study with a large sample size. Rahmanian et al. (2015) on his study reported that one year should be given in minimum to collect the series of samples, analyze the trends and monitor the reliability of water. However, this study was done with a small sample size and only the limited physico-chemical parameters were studied.

The weighted arithmetic index can be influenced more by any parameters far above or far below the WHO guidelines, than that of just above or below the guideline value. The results of the weighted arithmetic water quality index were significantly influenced by parameters like pH, iron and ammonia concentration. The average WQI value is the cumulative result of all the given parameters that concluded both bottled water and jar water has good water quality with values 13.4 and 6.10 respectively (Fig. 3). However, on sample-wise calculation, all the jar water samples have WQI values less than 11 indicating excellent water quality. On the other hand, 4 bottled water samples have the WQI value ranging from 25-50 indicating good water quality and remaining eleven samples have WQI values less than 11 indicating excellent water quality. The result of weighted arithmetic WQI which is the cumulative result of each water quality parameter was good. Overall, the water quality of jar water was excellent (2.09 - 10.80) and bottled water was both excellent and good (2.02 – 48.47) as per the weighted arithmetic index method.

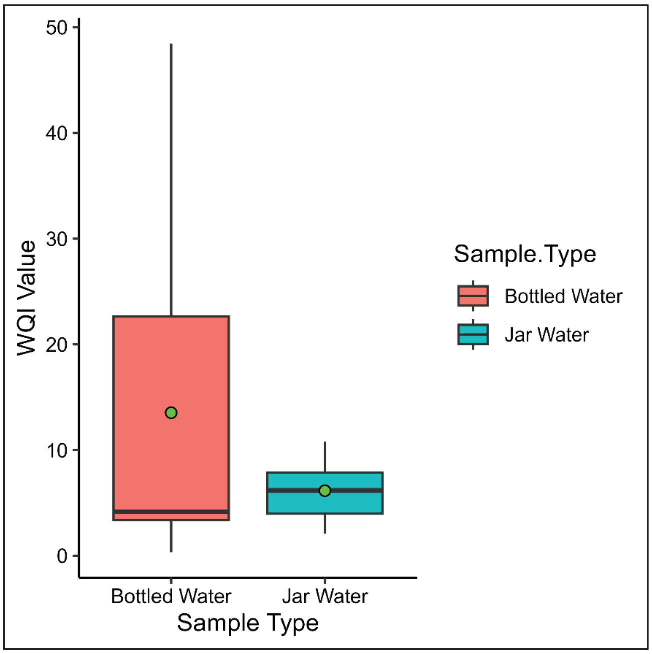

Figure 3: The WQI value of water samples of Jar and bottled water collected from Kathmandu Valley

Conclusion

Among the sampled bottled and jar water from the Kathmandu Valley, the values were found to be within the limits of NDWQS and WHO guidelines except for pH for bottled water and iron concentration in both jar and bottled water. Microbial test i.e., MPN test confirmed the absence of total coliforms in both the bottled and jar water. The Drinking Water Quality Index along with MPN test assures that both jar and bottled water were found to be safe for drinking in Kathmandu Valley. However, regular monitoring and assessment on available and assessable drinking water is necessary seasonally.

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Resilience Under Threat: Climate Change Impacts and Adaptive Responses of Nepalese MSMEs

Lalit Pathak[1], Rabin Malla[1], Binaya Kumar Lamichhane[2,3], Amod Mani Dixit[2,3,4]
[1] Center of Research for Environment, Energy and Water (CREEW), Baluwatar, Kathmandu, Nepal
[2] International Center for Applied Sciences (ICAS), Chakupat, Lalitpur, Nepal
[3] Universal Engineering and Science College (UESC), Chakupat, Lalitpur, Nepal
[4] National Society for Earthquake Technology-Nepal (NSET), Bhainsepati, Lalitpur, Nepal
*Correspondence: lalit@creew.org.np

Abstract

Nepal hosts over 923,000 registered businesses, with approximately 90% classified as Micro, Small, and Medium Enterprises (MSMEs). These businesses contribute to 45% of national employment, making them vital to economy. However, MSMEs face a significant financing gap, and climate change poses severe risks, particularly in sectors such as Non-Timber Forest Products (NTFPs), tourism, and aquaculture. The National Economic Census (2018) reports that climate change contributes to 1.8% of businesses failing to meet market demand, while 1.5% operate below full capacity due to climate-related factors. This study assesses MSME awareness of climate change, challenges, and impacts on production, costs, and raw material supply. Data were collected from 482 respondents across 16 districts in September 2024, revealed that most MSMEs are aware of climate change, yet struggle to adapt due to financial and resource constraints. Although awareness did not significantly differ between genders, a statistically significant difference was observed across age-groups. Key challenges include unpredictable weather patterns, increased pests and diseases, and declining raw material availability. The findings underscore the urgent need for targeted support to help MSMEs adapt to climate change. Policy recommendations include expanding access to climate finance, implementing capacity-building initiatives, and promoting market diversification strategies to enhance MSME resilience.

Keywords: *Adaptation strategies, Climate change, MSMEs, Resilience, Sustainable practices*

Introduction

Micro, Small, and Medium Enterprises (MSMEs) are crucial to Nepal's economy, contributing significantly to employment, poverty alleviation, and local economic development. These enterprises represent approximately 90% of the nation's 923,000 registered businesses (National Economic Census, 2018) and account for 45% of all employment (Neupane, 2017; NRB, 2019). However, despite their economic importance, the long-term sustainability of MSMEs is increasingly threatened by climate change and its disruptive impacts on operations, supply chains, and business value chains. Given Nepal's vulnerability to climate-induced hazards such as floods, droughts, landslides and erratic weather patterns (Amadio et al., 2023; Nepal et al., 2021; Pathak et al., 2023, 2025). MSMEs, especially those in sectors like agriculture, Non-Timber Forest Products (NTFPs), tourism, and aquaculture are disproportionately affected. These enterprises often lack the financial and technical ability to effectively adapt and recover from climate-related disruptions, placing their survival at risk.

A major barrier to adaptation is the significant financing gap. The financing needs of MSMEs are projected at $3.6 billion, but only $731 million is currently accessible (UNESC, 2020). This funding shortfall restricts MSMEs' ability to invest in climate-resilient infrastructure and adaptation strategies, leaving them more exposed to climate risks. Furthermore, the country's diverse geography worsens the vulnerability of these businesses. For example, small enterprises found in the lowland districts face greater risks from flooding, while businesses in the mid-hill regions are more susceptible to droughts and landslides.

Globally, MSMEs are recognized as being particularly vulnerable to climate change due to their small size, limited resources, and dependence on climate-sensitive sectors such as agriculture, fisheries, forestry, and tourism (Khan et al., 2020;). Numerous studies have shown that MSMEs in developing countries often face increased operational challenges from extreme weather events, shifting ecological conditions, and resource scarcity (CSR Asia, 2011; Gamage et al., 2020). For instance, in Bangladesh, MSMEs were found to be more exposed to climate-induced risks, but their limited access to finance and lack of adaptation knowledge prevented effective responses (Bank, 2020; Khatun et al., 2021).

While larger enterprises in Nepal have begun implementing climate adaptation strategies(PwC, 2023; UNDP, 2016), MSMEs face substantial challenges in this regard due to financial constraints and a lack of adequate knowledge (Neupane, 2017). The USAID Biodiversity (Jal Jangal) Business Perception Study (2021) reports that NTFPs and aquaculture sectors are particularly affected by climate change, with businesses in these industries struggling with pests, diseases, and the declining availability of raw materials. Despite increasing awareness about the need for adaptation, there is limited empirical research on how MSMEs perceive and respond to climate risks and the specific adaptation strategies they are employing. Existing studies tend to focus on larger enterprises or single sectors, creating a gap in understanding how climate change impacts MSMEs across different districts and sectors in Nepal (Bhattarai et al., 2023; Neupane, 2017).

This study aims to address this gap by providing a comprehensive assessment of MSMEs' awareness of climate change, the challenges they face, and the adaptation strategies they employ. Furthermore, it looks to explore how climate change impacts MSME operations, production, and raw material availability, while also examining the role of financial and policy support in enhancing their resilience. By focusing on a broad range of districts and sectors, this research offers crucial insights into the vulnerability of MSMEs to climate risks and provides evidence-based recommendations for policy interventions that can support their adaptation and long-term sustainability.

Materials and Methods

Study Area

The study was conducted across 16 districts of Nepal, selected to represent a diverse cross-section of the country's geographical, climatic, and economic zones (Figure 1). These districts spanned five provinces: Karnali, Lumbini, Bagmati, Gandaki, and Sudurpashchim Province, covering both hill and Terai (plains) regions. The districts were chosen based on their economic activity, vulnerability to climate change, and the presence of Micro, Small, and Medium Enterprises (MSMEs). The selected districts included a mix of urban centers, peri-urban, and rural areas, ensuring a broad representation of MSMEs in sectors such as agriculture, tourism, Non-Timber Forest Products (NTFPs), and aquaculture.

Survey Design

The survey design followed a structured format with objective questions aimed at gathering quantifiable data on MSME beliefs, climate change awareness, and adaptive strategies. The questionnaire was divided into three main sections: (1) Awareness of climate change, (2) Challenges faced by MSMEs due to climate change, and (3) Impacts on production, costs, and raw material supply. Closed-ended questions were used to measure the level of awareness and impact beliefs, while multiple-choice questions captured specific challenges and adaptation strategies. Open-ended questions were included to gather more insights into how MSMEs are adapting to climate change and what external support they need.

A total of 500 respondents were initially selected using a two-stage sampling approach. First, stratified random sampling was applied at the district level to ensure broad geographic representation across 16 districts. The number of businesses surveyed per district ranged from 15 to 30, depending on the relative size and economic importance of the MSME sector in each area. Within each selected district, convenience sampling was used to identify and survey MSMEs, based on accessibility and willingness to participate. This approach was adopted

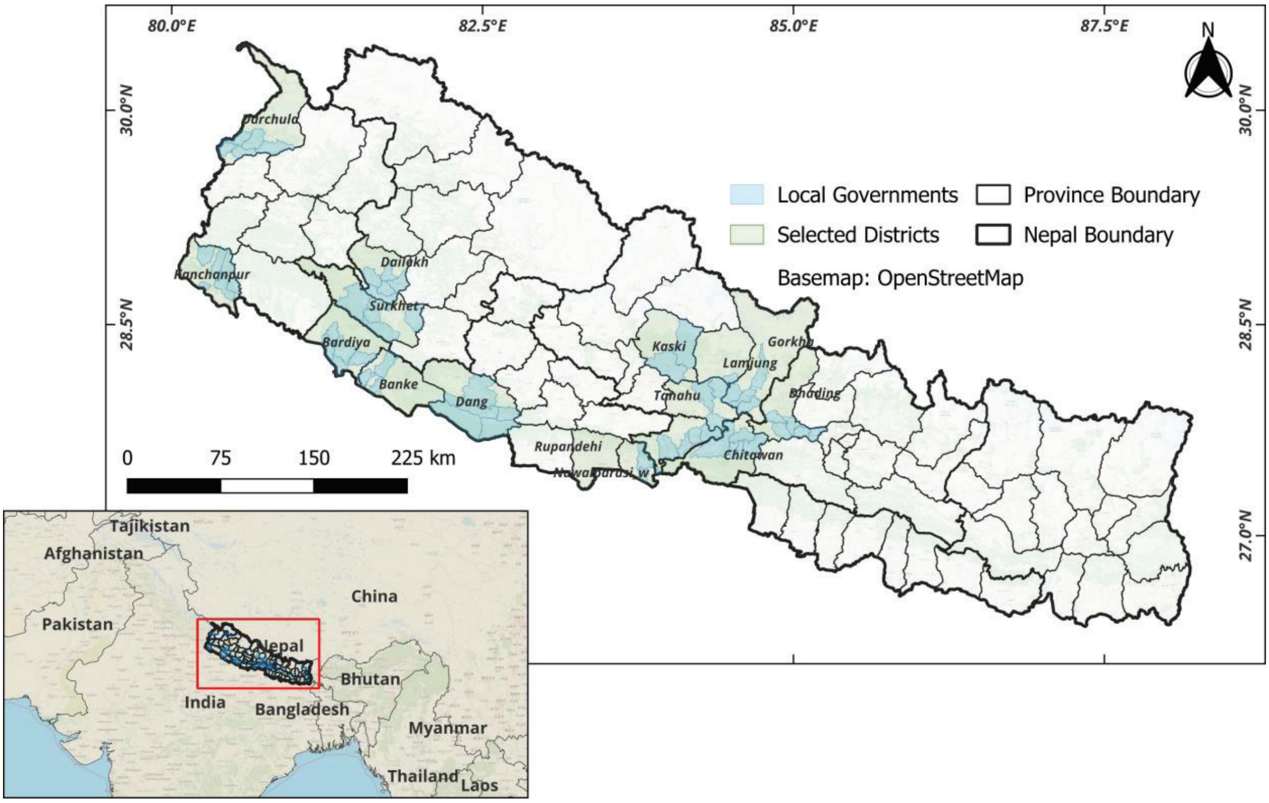

Figure 1: Map of the Study Area Depicting Districts and Local Governments Where Surveys have been Conducted

due to logistical and time constraints in the field. Out of 500 distributed questionnaires, only 482 fully completed responses were included in the final analysis, with incomplete or partially answered forms excluded. Gender representation was also considered; notably, 68% of respondents were women, reflecting the high level of female ownership and involvement in Nepal's MSME sector.

Data Collection and Analysis

Data collection was conducted in September 2024. The survey was conducted in-person with the help of trained enumerators. To ensure consistency and accuracy, enumerators were trained to explain the survey questions in Nepali or local dialects as needed, and respondents were assured of confidentiality. Indicators of impact included changes in productivity, supply chain disruptions, raw material availability, and income fluctuations. Adaptation indicators included practices such as adoption of the 3Rs, renewable energy use, and green certification. Vulnerability was inferred from factors such as business age, experience, resource dependence, and location-specific climate exposure.

The survey responses were processed using both quantitative and qualitative analysis methods. For closed-ended questions, statistical analysis was performed using Google Colab. Descriptive statistics, such as frequencies, means, and standard deviations, were used to summarize the data. Inferential statistics, including Chi-square tests were applied to examine the relationship between different. Open-ended questions were analyzed thematically, finding key patterns and themes related to adaptive strategies and climate change impacts. The results of the quantitative analysis were complemented by the qualitative insights to offer a comprehensive view of MSMEs' responses to climate change.

Results and Discussion

Descriptive Statistics

The survey captured 482 responses from MSMEs across 16 districts in Nepal, providing a comprehensive demographic and operational profile. Figure 2 illustrates the age distribution, gender representation, and business experience of respondents. Age distribution among respondents shows that most (50%) were aged 30–40, followed by 27.39% aged 41 or older, and 22.61% under 30. The dominance of middle-aged entrepreneurs, coupled with the significant participation of women, underscores the sector's capacity for innovation and inclusive growth. However, the relative youth of many businesses also point to potential vulnerabilities, particularly in the face of external challenges such as climate change.

Women comprised 67.84% of respondents, emphasizing their significant contribution to the MSME sector, particularly in micro and small enterprises. Their participation underscores the role of women entrepreneurs in driving economic and social empowerment. Regarding business experience, 42.12% of respondents reported 5–10 years in business, while 37.14% had less than 5 years. Only 10% had over a decade of experience, indicating that most MSMEs in the survey are relatively young businesses. These findings highlight the potential challenges and opportunities for MSMEs in navigating growth and sustainability amidst the increasing impacts of climate change.

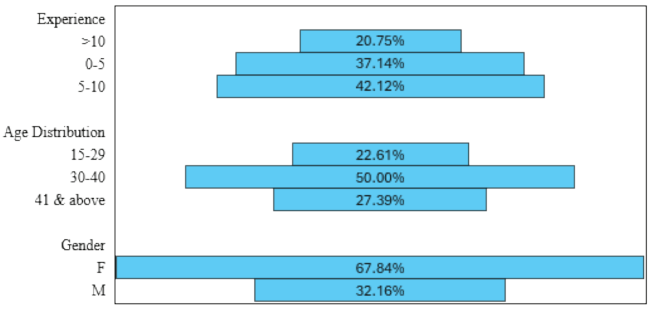

Figure 2: Descriptive Statistics of Respondents (482 MSMEs) Across 16 Districts in Nepal

The results underline the pressing vulnerabilities within the sector, particularly in terms of productivity losses and rising operational costs, aligning with findings from other developing regions where MSMEs are disproportionately affected by climate-induced risks (Ghimire, 2011; Nepal & Kadayat, 2024). Despite widespread awareness of climate change, the uptake of initiative-taking adaptation measures stays limited, highlighting a significant gap in preparedness and action. This discrepancy calls for targeted interventions to enhance the adaptive capacity of businesses, particularly in the face of resource scarcity, which was a predominant concern in this study, with 65% of businesses reporting decreased raw material availability. The significant association between age and climate change awareness among MSME owners, with younger entrepreneurs (15–29 age group) showing higher levels of awareness. This aligns with global observations that younger demographics tend to be more engaged with climate issues, possibly due to greater exposure to environmental education and media (Spence et al., 2011). However, the relatively low awareness among older entrepreneurs highlights the need for targeted interventions to bridge this gap and ensure inclusive climate adaptation efforts.

Awareness of Climate Change

The survey results revealed varied levels of awareness about climate change among MSMEs. A total of 14.32% of respondents reported being well-informed about climate change and its potential impact on their businesses. The majority, 65.56%, indicated having limited awareness, suggesting a basic understanding but insufficient knowledge for informed decision-making. Meanwhile, 20.12% of respondents admitted having no knowledge of climate change or its impacts, highlighting a significant gap in awareness within a substantial part of the MSME community.

Figure 3: Response to the Question" Are you aware of impact of cc on your enterprises?"

Statistical analysis further examined the relationship between demographic factors and awareness levels. The p-value (0.1848) from the chi-square test for gender and awareness was greater than the 0.05 significance threshold, indicating no statistically significant association. This implies that differences in awareness levels between males and females are likely due to random variation rather than an underlying gender-based factor. Conversely, the chi-square test for age groups yielded a p-value of 0.0414, which is below the 0.05 threshold. This result shows a statistically significant association between age group and climate change awareness, suggesting that awareness levels vary across different age categories, with some groups potentially being more informed than others. The 15-29 age group shows significant representation in both "Informed" and "Little Informed" categories. 41 & above age group has fewer "Informed" respondents compared to other age groups, suggesting a potential gap in awareness in this category.

The levels of adaptation to climate change within the MSME sector in Nepal vary significantly, with businesses largely falling into the "basic" and "managed/intermediary" levels of preparedness. At the basic level, many businesses show limited understanding of climate change and its potential impact, often lacking the knowledge required to mitigate risks (NRB, 2019). The fact that over 63% of businesses report being aware of climate change but do not take substantial action suggests

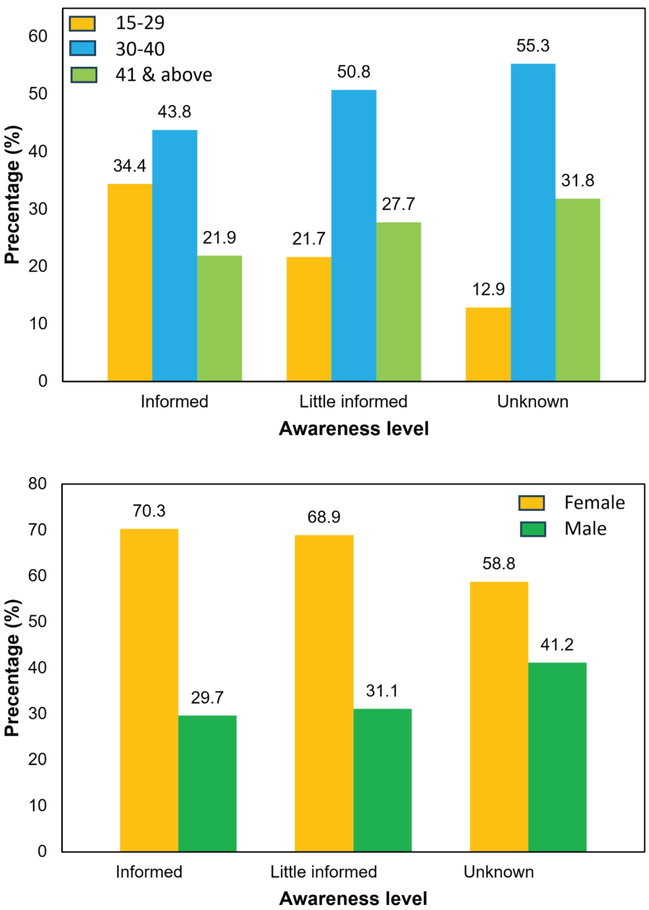

Figure 4: Distribution of MSMEs by Gender and Age Group Across Awareness Categories

that awareness alone is insufficient without access to the necessary resources and technical support. This finding resonates with literature from other regions, where smaller businesses often struggle with financial constraints and limited capacity for implementing adaptive technologies (Chhetri et al., 2012; Hokmabadi et al., 2024).

Common Challenges Faced

Nepalese businesses are becoming increasingly aware of the impacts of climate change on their operations. The majority of participants reported experiencing the effects of climate change, with changes in temperature and rainfall being identified as the key climate hazards affecting their businesses. In the past five years, businesses have met various climatic challenges, with the most prominent being extreme weather events. According to survey responses, the primary climatic extremes faced by businesses include floods (26.28%), droughts (10.36%), loss of natural resources (20.94%), diseases and insect infestations (16.36%), and other unclassified events (25.95%).

These climate-related challenges have had a significant impact on business operations. The most common effects reported include a decrease in production (28.57%), reduced access to raw materials (17.58%), an increase in production costs (13.49%), supply chain disruptions (21.88%), and difficulties in market access (16.38%). A small percentage of businesses (2.10%) reported no impact from these climatic challenges.

When asked about the aspect of their business most impacted by climate change, most businesses reported that the availability of raw materials was the most affected, with 35.24% of respondents showing it as a major concern. Another massive part of businesses (45.91%) noted that production quality was heavily affected by climate change. A smaller percentage of businesses pointed to market access (0.99%) and transportation and market access (6.65%) as being disrupted. Additionally, 8.93% of respondents showed that both availability of raw materials and production quality were jointly affected by climate-related changes.

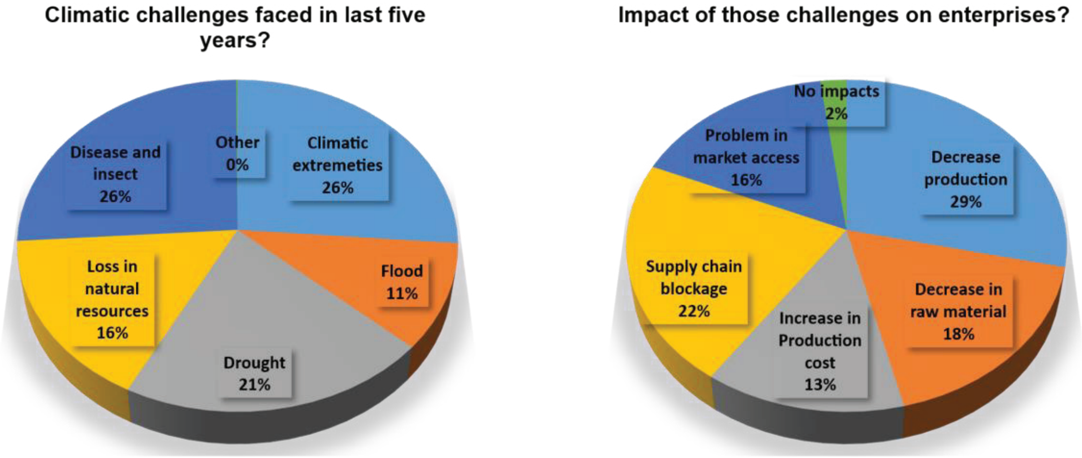

Figure 5: Impact of Climate Change on MSMEs

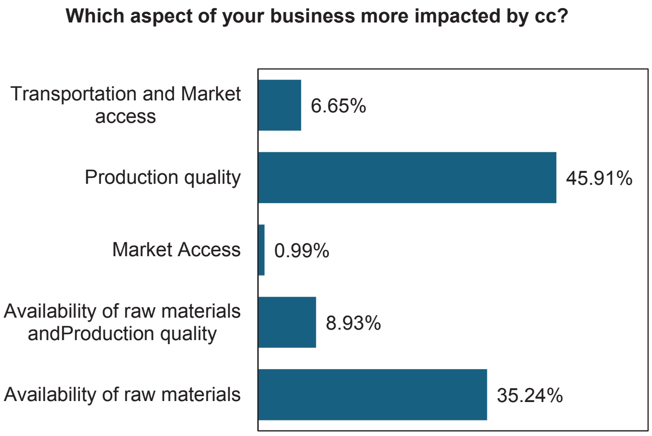

Figure 6: Primary Business Areas Affected by Climate Change

The significant impact of extreme weather events, such as floods and droughts, on MSME productivity is consistent with studies from Southeast Asia, where resource scarcity due to climate change is a primary concern (Gannon et al., 2018; Panda, 2021; Trabacchi & Stadelmann, 2013). The survey revealed that raw material availability and production quality were the most affected areas, with 35.24% of businesses showing raw material shortages as a major concern. This aligns with findings in other agrarian economies, where agricultural-dependent businesses are highly vulnerable to disruptions in natural resource availability (Khan et al., 2020; PwC, 2023). Nepal's vulnerability is further worsened by its socio-economic context, marked by high levels of poverty, a dependence on subsistence agriculture, and geographical challenges such as its fragile ecosystems and undulating topography (Government of Nepal, 2022). These factors make the country's MSMEs particularly susceptible to climate risks, highlighting the need for more tailored, region-specific adaptation strategies.

Business Responses and Financial Impacts of Climate Change

In response to questions about adopting new techniques to mitigate the impact of climate change, many businesses expressed interest in exploring and implementing new methods to better cope with climate change challenges. Specifically, 370 businesses said they would have a willingness to adopt new techniques to address climate change impacts.

When asked about the monetary impact, 306 businesses reported that climate change has increased their production costs. Additionally, 304 businesses acknowledged that climate change-related factors have influenced their income, underscoring the economic burden posed by climate change on business operations.

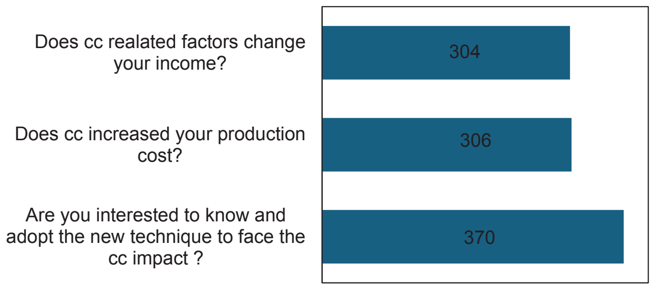

Figure 7: Respondents Responses on Financial Impacts of Climate Change

In response to climate change, businesses have implemented various strategies to mitigate its effects. Among the most common strategies, Sustainable Collection Technologies were adopted by 91 businesses, while Green Certification was pursued by 18 businesses as a way to demonstrate their commitment to sustainability. A substantial number of businesses (275) have embraced the 3R (Reduce, Reuse, Recycle) principle as part of their operations. Additionally, 130 businesses have turned to renewable energy solutions to reduce their carbon footprint. However, 17 businesses reported that they have not implemented any specific strategies to address climate change.

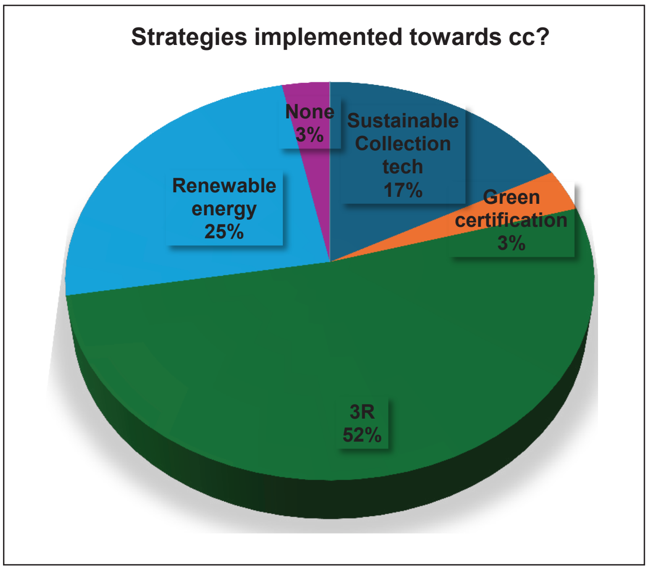

Figure 8: Strategies Implemented Towards Climate Change

The study also revealed notable regional disparities in the impact of climate change. Flooding, for example, was more prevalent in lowland districts (70%) than in mid-hill districts (40%). This geographic variation underscores the necessity of localizing adaptation measures to account for the distinct vulnerabilities of different regions within Nepal. Tailored policies and programs, informed by regional climate risks, are essential to ensuring that adaptation efforts are both effective and fair.

Although the adoption of adaptation strategies is still limited, the study found that many MSMEs are interested in exploring new methods to cope with climate challenges. This willingness to adapt, however, often faces barriers related to access to information, technical ability, and financial resources. The adoption of the 3R (Reduce, Reuse, Recycle) principle by a significant number of businesses reflects a preference for low-cost and readily implementable solutions. However, the more advanced adaptation strategies, such as the adoption of renewable energy and sustainable collection technologies, remain far less widespread. This pattern is consistent with findings from global studies that suggest smaller businesses often face difficulties in accessing the capital needed for transformative investments (Khan et al., 2020; Neupane, 2017; Thapa, 2015; UNDP, 2016).

Policy implications from this study are clear. To enhance the adaptive ability of MSMEs, policymakers must prioritize awareness programs that not only inform businesses about climate change but also equip them with the tools and knowledge necessary for effective adaptation. The Government of Nepal, along with development organizations, should focus on providing financial support and incentivizing the adoption of climate-resilient practices. The establishment of financial mechanisms, such as adaptation financing facilities, can help businesses overcome the upfront costs associated with adopting innovative technologies (NRB, 2019; PwC, 2023). Moreover, strengthening supply chain resilience should be a central focus, as climate-related disruptions in raw material availability and transportation are critical issues that threaten business continuity (Bhattarai et al., 2023).

The limitations of this study include the relatively small sample size in some districts and the short time frame for data collection, which may not fully capture the long-term impacts of climate change. Future research should explore longitudinal data to better understand the evolving climate risks faced by MSMEs and the long-term sustainability of their adaptation efforts. Additionally, further studies could investigate the specific barriers to the adoption of advanced adaptation strategies and the effectiveness of government support programs in fostering climate resilience.

Climate change poses a significant threat to MSMEs in Nepal, but it also presents opportunities for growth through effective adaptation. As the study proves, businesses that are aware of the risks yet struggle with implementation need tailored interventions to overcome the barriers they face. Policymakers and development organizations must take a more proactive role in supporting these businesses through financial mechanisms, knowledge-sharing platforms, and community-based approaches. This collaborative effort, involving both public and private sectors, will be critical in building the resilience of Nepal's MSME sector and ensuring its long-term sustainability in the face of climate change. By fostering a collective approach to climate resilience, Nepal can better equip its MSMEs to navigate the challenges of a changing climate and contribute to national development goals.

Conclusion

This study highlights the significant vulnerabilities of Micro, Small, and Medium Enterprises (MSMEs) in Nepal to climate change, emphasizing the sector's limited adoption of proactive adaptation measures despite widespread awareness of climate-related risks. The findings reveal that climate change is already adversely affecting MSMEs through reduced productivity, increased operational costs, and disruptions in the supply of raw materials. While some businesses have initiated basic adaptation efforts, the overall level of preparedness remains inconsistent, underscoring the urgent need for targeted interventions to enhance resilience.

A key insight from this research is the geographical variation in climate impacts, with regions such as lowland districts facing heightened risks like flooding. This regional disparity underscores the importance of context-specific adaptation strategies tailored to the unique vulnerabilities of different areas. Furthermore, while MSMEs express a willingness to adopt advanced adaptation measures, significant barriers—such as limited access to financial resources, technical knowledge, and institutional support—hinder their ability to implement these strategies effectively.

The findings have critical implications for policymakers and stakeholders. First, there is a need to raise awareness about climate risks and adaptation strategies among MSMEs. Second, financial mechanisms, such as grants, low-interest loans, or climate risk insurance, should be established to support businesses in adopting resilient practices. Third, localized adaptation efforts must be prioritized, taking into account the distinct vulnerabilities of different regions. Finally, strengthening supply chain resilience and fostering collaboration between government agencies, development organizations, and the private sector will be essential for building a climate-resilient MSME sector.

To build on this study, future research should focus on longitudinal analyses to track the long-term impacts of climate change on MSMEs and evaluate the effectiveness of adaptation measures over time. Sector-specific studies, particularly in agriculture, tourism, and manufacturing, would provide deeper insights into the unique vulnerabilities and adaptation needs of different industries. Additionally, further exploration of the barriers to adopting advanced technologies and the role of institutional support mechanisms is crucial for designing targeted interventions. This study serves as a foundational contribution to understanding the climate adaptation challenges faced by Nepalese MSMEs. However, sustained research efforts and proactive policy measures will be essential to ensure the sector's long-term sustainability and growth in the face of a changing climate. By addressing these challenges, Nepal can unlock the potential of its MSME sector as a driver of economic resilience and inclusive development.

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Conflict of Interest

The authors declare that there are no conflicts of interest in the publication of this article.

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Climatic Trends and Their Impacts on High-Altitude Ecosystems in Nepal: Implications for Biodiversity and Ecosystem Services

Narayan Prasad Ghimire[1], Puja Ghimire[1], Raju Chauhan[2*], Sudeep Thakuri[3,4]
[1]Central Department of Botany, Tribhuvan University, Kirtipur, Nepal
[2]Department of Environmental Science, Patan Multiple Campus, Tribhuvan University, Lalitpur, Nepal
[3]Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal
[4]Graduate School of Science and Technology, Mid-West University, Surkhet, Nepal
*Correspondence: raju.chauhan@pmc.tu.edu.np

Abstract

Nepal's high-altitude ecosystems (>3000 m asl) are experiencing unprecedented impacts from climate change, with profound implications for biodiversity conservation and ecosystem services. This systematic review synthesizes evidence from 72 peer-reviewed studies to assess climatic trends and their ecological consequences in the Nepal Himalaya. Temperature records from 1976-2015 reveal significant warming trends, with higher elevations experiencing more pronounced increases (0.045°C y^{-1} for maximum temperatures). Climate projections indicate continued warming of 1.2-4.2°C by the 2080s under RCP8.5 scenarios, with precipitation increases of 11-23% by 2100. These climatic changes are driving cascading ecosystem effects. Glacial retreat has accelerated, with 15% reduction in glacier surface area over five decades and upward snowline shifts of 182 m in the Everest region. Freshwater ecosystems face mounting pressures from altered hydrology and increased glacial lake outburst flood risks. Forest ecosystems exhibit treeline advance (2.61 m y^{-1} for *Abies spectabilis*), phenological shifts, and upslope vegetation migration. Biodiversity impacts include altered species distributions, invasive species expansion, and habitat degradation for endemic species. The convergence of warming temperatures, changing precipitation patterns, and extreme weather events poses significant threats to Nepal's mountain biodiversity hotspots and ecosystem services. These findings present the urgent need for integrated climate adaptation strategies and science-based conservation approaches to safeguard these vulnerable ecosystems. Nepal's mountainous regions serve as both indicators of global climate change and critical refugia requiring immediate conservation attention to maintain ecological integrity.

Keywords: *Biodiversity, Forests, Precipitation, Temperature, Water*

Introduction

The world's biodiversity is cradled and protected by mountains (Rahbek et al., 2019), hosting nearly half of the planet's biodiversity hotspots. They are home to a diverse range of species, including many that are endemic, rare, or threatened. Diversity of species is exceptionally high in mountains and outside of Antarctica that covers 12–30% of Earth's land surface. Himalayan slopes occupy the majority of Nepal's land area creating enormous environmental heterogeneity. The distinct physiographic and topographic features of Nepal harbor a diverse range of western niches for diverse flora and fauna. Stretching approximately 800 km from east to west and 144-240 km from north to south, the Himalaya regions exhibit a remarkable blend of Sino-Japanese characteristics (Stearn, 1960). Located in Southeast Asia, this vast region stretches from the Indo-Gangetic basin to the Himalayan range and the Tibetan plateau. The intricate topography of Nepal is primarily responsible for the presence of a significant amount of plant endemism in the country from a phytogeographical perspective (Schickhoff, 2005). Tiwari et al. (2019) reported that the Nepal Himalaya is home to 312 endemic species of flowering plants.

Concerns regarding the present and potential effects of climate change in the region are heightened by the Himalayan region's delicate terrain, which makes it extremely vulnerable to natural calamities (Cruz, 2007). The mountain climate differs due to its topography complexity, gradient complexity, short-term oscillations, physical parameters as air pressure, oxygen availability (Rahbek et al., 2019).

According to Ghosh (2009) the Himalayan region is recognized as the most striking mountain chain exposed to climatic perturbation. Due to the high elevation and rugged landscape of the area, there is a phenomenon of geographic isolation, restrictions in species distribution, and reduced human influence. Collectively, these factors heighten the system's vulnerability to the effects of climate change (Zomer et al., 2014) and this change in climate are miscellaneous encircling droughts, landslides, flood (Barnett et al., 2005).

Mountain ecosystems posses a direct and indirect ecosystem services to the world population living in and around the high-altitude mountain regions (Liu et al., 2019). Mountain ecosystems provide a diverse array of valuable services, including essential resources such as food and timber, protection from natural hazards, cultural importance, and habitats that support biodiversity (Payne et al., 2017). Mountain ecosystems also play a vital role in supporting services such as nutrient cycling and regulating services, including climate control and natural hazard mitigation (Baral et al., 2017). Forest cover in these areas acts as a buffer zone, effectively mitigating the impact of natural hazards like landslides and avalanches, reducing the risk of flooding, preventing soil erosion, and promoting soil formation processes. Thus, the human beings are also well-benefited by the montane forest as it delivers the ecosystem services (Seidl et al., 2019)

Numerous studies highlight that global climate change has been occurring for an extended period, threatening the stability of societies and the resilience of both natural and managed ecosystems. Because of their isolated positions and marginalized status, Nepal's mountain villages are especially susceptible to the effects of climate change (Macchi et al., 2015). Notably, the mountainous regions of Nepal experience a higher magnitude of warming compared to the lower altitude areas (Shrestha & Aryal, 2011). The vegetation in mountainous regions is especially vulnerable to climate change due to its dependence on the cooler temperature characteristic of higher altitudes (Körner, 2003). Mountains offer a broad range of essential ecosystem services that support the well-being of people worldwide. However, these regions are highly susceptible to various stressors, resulting in global changes that threaten and degrade the ecosystems they sustain. This article aims to assess climatic trends and their impacts on Nepal's high-altitude ecosystems (>3000 m asl), with a particular focus on water resources, forests, and biodiversity.

Material and Methods

The study is based on a desk review of the published scientific literatures. Literatures were searched in Web of Science, Scopus, and NepJol database using relevant search strings such as 'climate change trends', 'climate change scenarios', 'climate impact ecosystem', 'Nepal Himalaya'. A total of 105 articles were downloaded from the three databases. After removing the duplications, 72 articles were found relevant to this study. The articles were reviewed to understand the trends, scenarios, and impacts of climate change on Nepal's high-altitude

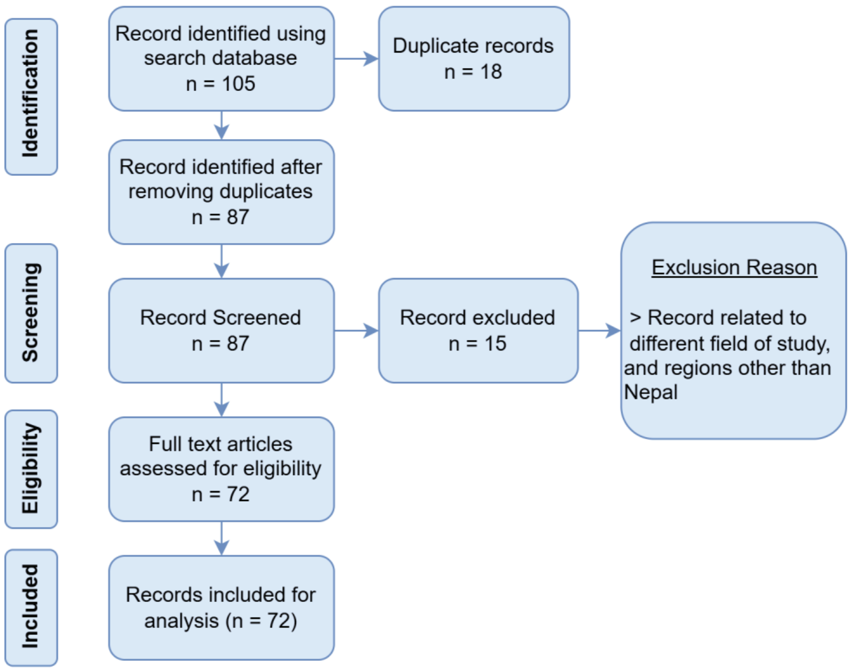

Figure 1: *PRISMA flow diagram illustrating the article selection process for the systematic review.*

ecosystems. The PRISMA flow diagram for the article selection is given in Fig. 1.

Results and Discussion

Climatic trends and variability in Nepal

Annual and seasonal trends of temperature and precipitation

According to Global Climate Risk Index (CRI) index 2021, Nepal is ranked as the 12th most vulnerable country. Over the few decades, the country has been experienced clear trend of increasing temperature (MoFE, 2021). In Nepal, the air temperatures exhibit distinct patterns throughout the year. The highest temperatures, ranging from 36 to 39°C on average, occur in May or early June, while the monsoon season brings more moderate temperatures. During December and January, the mean minimum temperatures fall below -3°C. Notably, the warming trend is more significant in Nepal's high-altitude regions, including the middle mountains and the high Himalayas.

Interestingly, a notable rise in minimum temperatures has been recorded exclusively during the monsoon season on the southern side of the Himalayas. This variation in minimum temperatures on both sides of the Himalayas is closely linked to reduced cloud cover and weakened downward longwave radiation (Yue et al., 2020). The average temperature trends per decade for various seasons were recorded as follows: 0.23°C for the annual average, 0.4°C for winter, 0.2°C for pre-monsoon, 0.3°C for monsoon, and 0.12°C for post-monsoon (Dhital et al., 2023).

In Nepal, about 80% of the annual rainfall occurs during the Indian summer monsoon season, which lasts from June to September (DHM, 2017). The average annual precipitation is approximately 1530 mm, with the heaviest rainfall recorded at elevations around 2000 m. In contrast, the northern regions of the Himalayan peaks experience drier conditions due to their rain shadow effect (DHM, 2015; 2017). During winter and spring, snow and rain are brought by westerly low-pressure weather systems originating from the Mediterranean Sea, with the northwestern part of the country being the most affected. Winter precipitation plays a crucial role in shaping the mass balance of glaciers in western Nepal. The precipitation has been experienced in decreasing order during the period of 1903-1982 and 1962-2002. The similar trend was followed by annual rainfall during 1903-1982, but the increasing trend was observed during the period of 1962-2002 and 1901-2002 (Karki et al., 2017).

Spatial variation of temperature and precipitation

The relatively rapid warming observed in Nepal since the mid-1970s can largely be attributed to significant warming rates in the Himalaya and Middle Mountain regions (Table 1). As a result, the mountainous region of Nepal appears to be amplifying the trend of regional warming, supporting the notion that alpine areas are highly sensitive to climate change. Shrestha et al., 1999 studied the variation of temperature from 1971 to 1994. The study revealed that before 1978, the temperature pattern was either stable or falling across all physiographic regions. In most of the country's region, the mean annual maximum temperature rose from 1997 to 1994. Maximum temperatures have increased in much of the middle ranges and High Himalayan region. Maximum temperatures are rising (albeit more so at higher altitudes), whereas minimum temperatures are falling at high altitudes while rising or positively trending at lower altitudes (Kattel and Yao 2013; Thakuri et al. 2019). A notable increase in near-surface air temperature and diurnal temperature range (DTR) has been observed at varying elevations up to 2566 m during the 1976-2015 period. Over the past four decades, the maximum air temperature exhibited a more significant increase (+0.045°C y^{-1}) compared to the minimum temperature (+0.009°C y^{-1}), resulting in a significant rise in DTR (+0.034°C y^{-1}) (Thakuri et al., 2019). Spatial analysis conducted by Kattel and Yao (2013) also confirms warming trends in most mountainous regions, with maximum temperatures experiencing a greater degree of warming compared to minimum temperatures, which show greater variability with positive, negative, or no change. In terms of maximum temperature, the pattern was inverse, with higher altitudes experiencing greater maximum temperatures and lower altitudes experiencing lower maximum temperatures (DHM 2017; DHM 2015; PAN, 2009; Salerno et al., 2015; Shrestha et al., 1999; Thakuri et al., 2019), signifying that higher altitudes are becoming warmer (Table 1). Over the last four decades, the northern side of the Himalaya has experienced more pronounced warming during night time compared to daytime, whereas the southern side has seen stronger warming during the daytime than at night (Yue et al., 2020).

Dhital et al. (2023) conducted a study on the annual and seasonal warming patterns across various physiographic regions of Nepal. The study found that Nepal's eastern region experienced more pronounced warming compared to the central and western regions, demonstrating greater climatic sensitivity, especially in the Khumbu region, which surrounds Mount Everest. All physiographic zones, namely the Terai, Siwaliks, Lower Hills, and Upper Hills, showed rising temperature trends throughout an altitude gradient, with corresponding rates of 0.15°C, 0.26°C, 0.68°C, and 0.57°C each decade. The average annual and seasonal temperature patterns revealed that the eastern part of the country experienced more warming compared to the central and western regions (Dhital et al., 2023; Thakuri et al., 2019).

In case of precipitation, it is found that the country experienced longer dry periods and reduced post-monsoon rainfall overall (Fig. 2); however, there were different trends in annual and high-intensity rainfall extremes between the eastern and western regions (Karki et al., 2017). The latter showed an increasing pattern while the former exhibited a moderate decrease. In addition, winter precipitation significantly dropped in the western region, suggesting a weakened impact of western disturbances.

Climatic change scenario of Nepal

Several studies have forecast varying degrees of future temperature rise. According to NCVST (2009), it is projected that temperatures will increase by 0.5 to 2.0°C by the 2030s, followed by a rise to 1.7 to 4.1°C by the 2060s, and further increasing to 3.0 to 6.3°C by the 2090s. The IPCC's 2007 report shows that by the 2050s, it is anticipated that the average temperature across the Asian landmass, including the Himalaya, will increase by around 3°C. Furthermore, by the 2080s, the projected temperature rise is expected to reach 5°C. Similarly, there is a projected increase of 10-30% in annual precipitation in this area by the year 2080 (IPCC, 2014). While the projected range of temperature increase may vary, multiple studies concur that temperatures will indeed rise in future (Bajracharya et al., 2018; Dahal et al., 2020; Khadka & Pathak, 2016; Krishnan et al., 2020; Meher et al., 2017). The Ministry of Environment's report (MoE, 2010) also

Table 1: Trends in Nepal's annual and seasonal temperatures (°C y^{-1}) from 1976 to 2015 (Thakuri et al., 2019).

		Terai plain	Siwalik	Middle Mountains	Himalaya	High Himalaya	Lower Stations	Higher Stations	All Nepal
		(T)	(S)	(MM)	(H)	(HH)	(LS)	(HS)	(Nepal)
		100-700 m	700-1500 m	1500 -2000 m	2000-4000 m	4000-8848 m	< 1000 m	>1000 m	70-2566 m
Winter	Tmax	-0.014 *	0.012	0.079 ***	0.064 ***	-	0.005	0.079 ***	0.030 ***
Pre-monsoon	Tmax	0.018	0.029 **	0.078 ***	0.051 ***	-	0.030 **	0.073 ***	0.051 ***
Monsoon	Tmax	0.023 ***	0.030 ***	0.065 ***	0.045 ***	-	0.029 ***	0.063 ***	0.046 ***
Post-monsoon	Tmax	0.014	0.020	0.068 ***	0.064 ***	-	0.024 **	0.069 ***	0.045 ***
Annual	Tmax	0.017 ***	0.028 ***	0.073 ***	0.058 ***	-	0.028 ***	0.072 ***	0.045 ***
	Tmin	0.017 ***	0.010 **	0.006	0.007	-	0.017 ***	-0.002	0.009 *
	Tmean	0.018 ***	0.021 ***	0.035 ***	0.030 ***	-	0.025 ***	0.032 ***	0.027 ***
	DTR	-0.004	0.021 ***	0.068 ***	0.053 ***	-	0.009	0.078 ***	0.034 ***

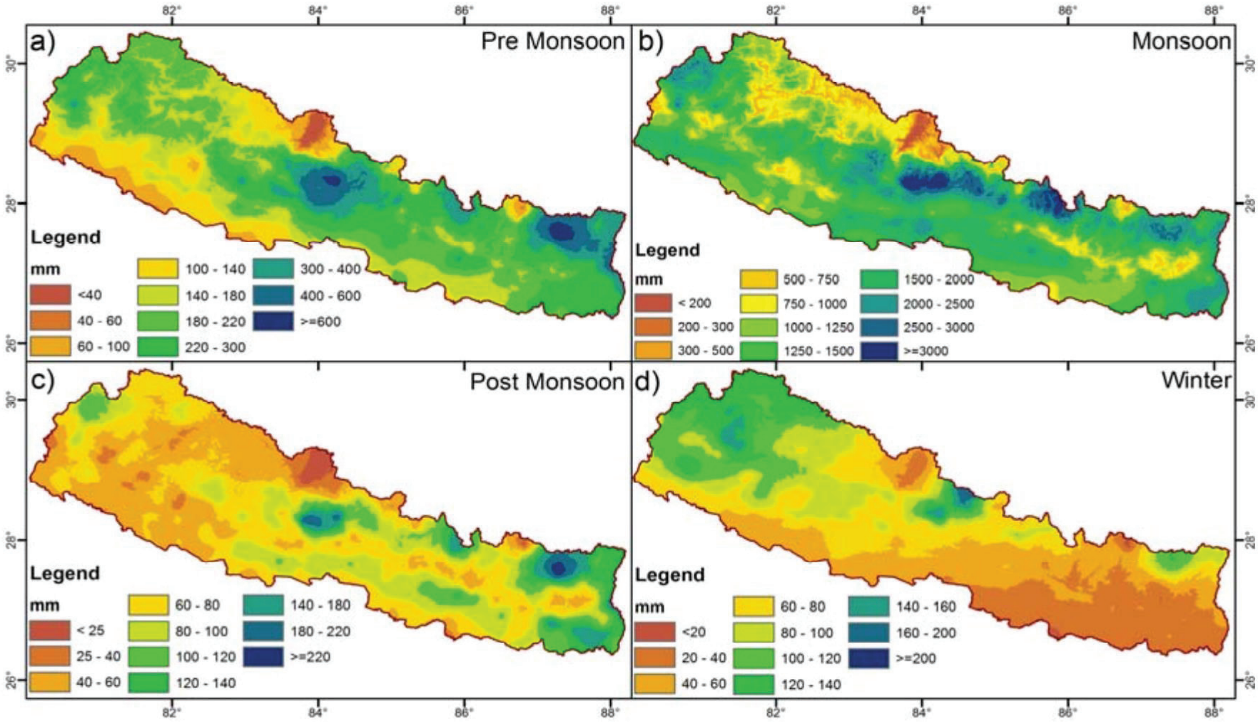

Figure 2: Spatial patterns of average seasonal precipitation (mm) for the periods of 1981-2010, depicting (a) Pre-monsoon, (b) Monsoon, (c) Post-monsoon, and (d) Winter seasons (Karki et al., 2017).

aligns with these findings, indicating a temperature increase of 1.4°C by 2030, 2.8°C by 2070, and 4.8°C by 2090. Furthermore, research indicates that Nepal is expected to experience a more rapid warming compared to the global average. According to the highest emission scenario, RCP8.5, Nepal could see an increase in temperature of 1.2 to 4.2°C by the 2080s, relative to the baseline period of 1986-2005 (WB & ADB, 2021).

The consensus among models regarding precipitation projections, and the significance of expected variations, is low for both winter and summer seasons (Solomon et al., 2007). However, in the context of the Nepal Himalaya, the majority of model projections indicate an increase in precipitation in future. Based on a recent projection (MoFE, 2019), it is anticipated that average annual precipitation will likely increase in both the medium-term (2016-2045) and long-term periods (2036-2065). During the medium-term period, average annual precipitation is expected to see a rise of 2-6%, while in the long-term period, it could increase by 8-12%. By the end of 2100, precipitation is expected to experience a further increase of 11-23%. In a study by Kadel et al. (2018) using CMIP5 models, future monsoon precipitation in the central Himalayas was examined. The study consistently showed a substantial increase in seasonal mean precipitation during the middle and late 21st century, regardless of the warming scenarios RCP4.5 and RCP8.5. In contrast, projections from the high-resolution PRECIS model in the Koshi Basin indicated an increase in the frequency and intensity of extreme climate events, such as dry days, consecutive dry days, and extremely wet days, with more significant changes expected in the southern plains compared to the northern mountainous regions. According to future projections, both annual precipitation and river discharge are expected to increase compared to the baseline. However, this increase will not be consistent across all seasons. According to Dahal et al. (2020), the post-monsoon season, which presently has the lowest recorded precipitation, is expected to receive even less rainfall in the future. This projected decrease in precipitation is likely to have a corresponding impact on river discharge, following a similar declining trend.

In the mountain and trans-Himalaya zones, a notable decrease in moderate rainfall days is anticipated (Rajbhandari et al., 2018). Additionally, warm days and nights are anticipated to be more frequent, while colder days and nights are anticipated to be less frequent. In the western region, warmer temperatures, extended monsoon seasons, and occasional rainfall events are expected throughout the year, including during typically dry months. The mountains will suffer major fluctuates in temperature, while the hills and plains are expected to witness the largest differences in precipitation (Dhaubanjar et al., 2020).

The Effects of climate change on high-altitude ecosystems

Mountain ecosystems are closely tied to the climate, and organisms have gradually adjusted to the climate in their specific regions. Climate change, particularly the changes in temperature and precipitation patterns, is to blame for the notable alterations seen in high-elevation areas. These changes serve as a prominent driving force behind the observed shifts in these areas. In different physiographic regions of Nepal, as a consequence of the warming trends, areas experiencing higher rates of warming also faced greater ecological impacts, including changes in water resources, phenology, and more (Fig. 3). In the context of global warming, the negative impacts are more pronounced in the Lower Hills, Upper Hills, and Mountains than in the Terai and Siwaliks (Dhital et al., 2023). The alternation in temperature and precipitation pattern causes retreating the glaciers, change in snow cover (Scherler et al., 2011; Thakuri et al., 2014; Khadka et al., 2020), increasing the number and size of glacial lakes (Khadka et al., 2018), glacial-lake outburst flooding (Khadka et al. 2021; Byers et al. 2019; ICIMOD, 2011), the water towering (Immerzeel et al., 2010), treeline advance (Gaire et al., 2014; Schickhoff, 2005), phenological change (Shrestha et al., 2012) and changed species interactions, greater pressure on species selection, and higher extinction risks (Dillon et al., 2010). Mountain ecosystems are highly vulnerable to changes in temperature and precipitation patterns, and are expected to face significant biotic disruptions in the coming years (Zomer et al., 2014).

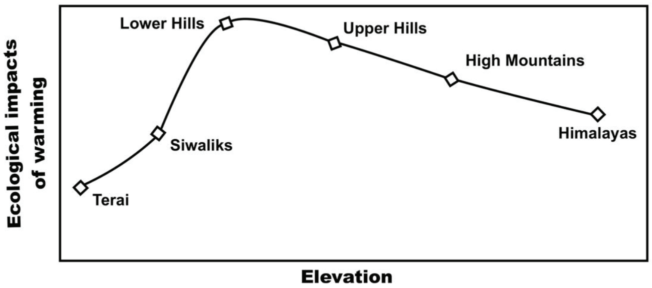

Figure 3: *Possible ecological impact of climate change with altitude (Adapted from Dhital et al., 2023)*

Fresh water ecosystem

The climate change impact on rapid melting of glaciers was observed in high-mountain of Nepal. According to Thakuri et al. (2014), the glaciers in the Mount Everest (Sagarmatha) region have experienced a reduction of 13% in surface area and 6.1 m y^{-1} in glacial length from 1962 to 2011, while the snowline has shifted upward by 182 m. The Himalayan region is seeing the effects of climate

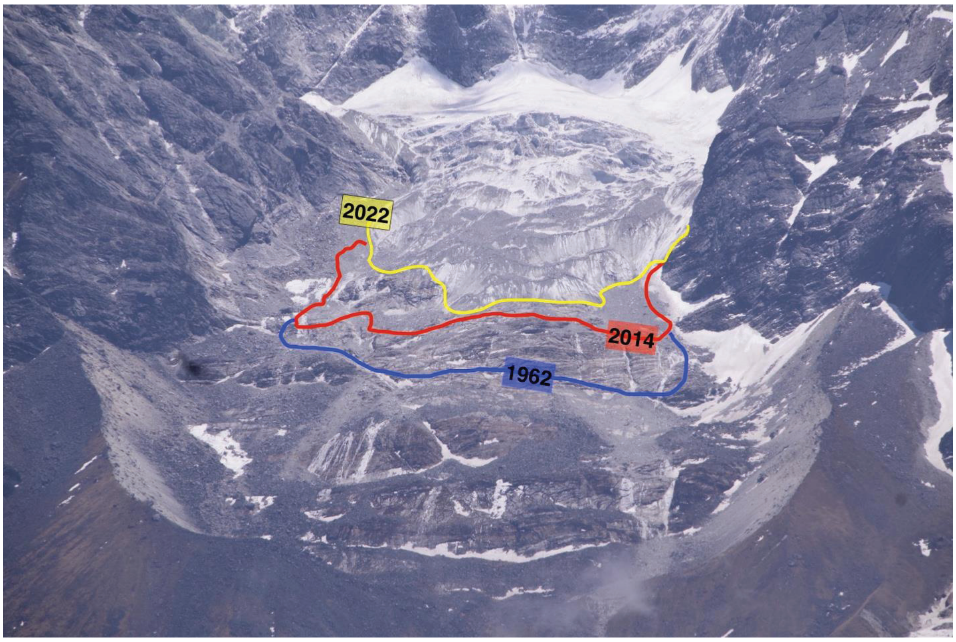

Figure 4: Photo of a glacier located on the north-west slope of Mount Thamserku (in front of Syangboche), taken in 2022, showing the glacier extend in 1962 (from satellite imagery) and 2014 (photo). The photo clearly marks the glacier ice loss (Photo credit: Sudeep Thakuri, 2022).

change, with many glaciers retreating more quickly (Fig. 4 & 6) than those in other mountain ranges (Thakuri et al., 2014; Bajracharya et al., 2023; Shrestha et al., 2017), thereby increasing the extent of glacier lakes and increasing glacier lake outburst floods risks (Fig. 5a and 5b). Studies showed that there has been a significant upward shift in the permanent snowline (Thakuri et al. 2014; Khadka et al. 2020). In the last fifty years, the Nepal Himalaya has experienced an overall loss of about 15% of its glacier surface area.

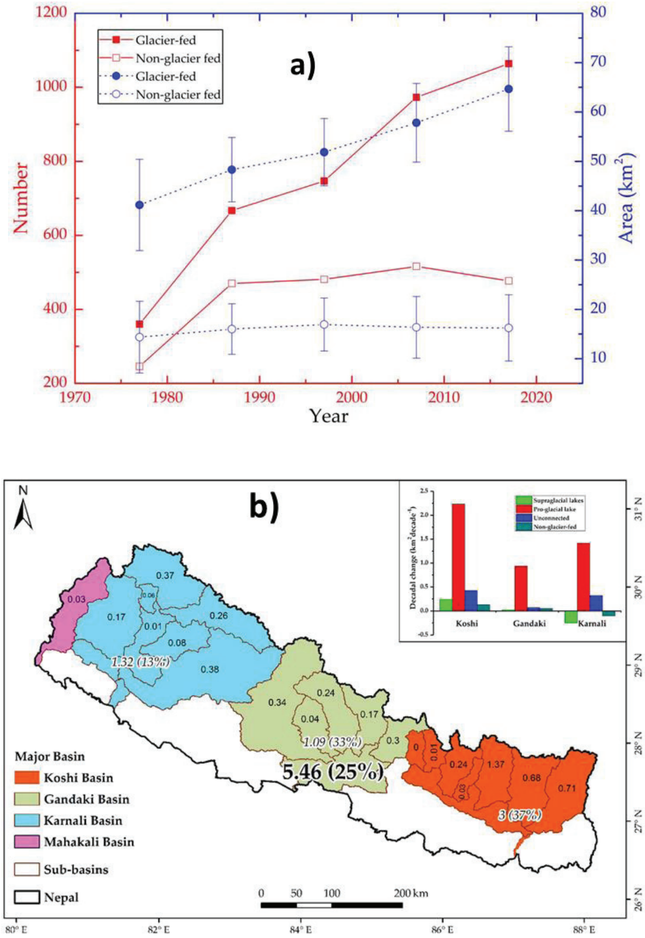

Figure 5: Status of glacier lakes in Nepal. a) Changes in the number and surface area of glacier-fed and non-glacier-fed lakes and b) Expansion of glacial lakes from 1987 to 2017 (km^2 $decade^{-1}$) in various sub-basins of Nepal (Khadka et al., 2018).

Paudel & Andersen (2011) found a reduction in the volume of annual snowfall and alterations in the seasonal snowfall patterns in the Trans-Himalayan Region of Nepal, based on MODIS data. These changes were linked to ongoing climate change and its associated variability. Alterations in the cryosphere can lead to hydro-ecological impacts, such as the drying up of springs and lakes. These changes can have major implications for water availability and food production, potentially leading to water stress. As a result, the costs associated with water collection and storage may increase (Manandhar et al., 2012). Climate change has affected the upstream snow and ice reserves in the Hindu Kush Himalaya (Shrestha & Aryal 2011). A study conducted in the Khumbu (Everest) Himalaya revealed that the lower limit of permafrost has experienced an elevation rise of 100-300 m between 1973 and 1991, followed by a period of stability at least until 2004 (Fukui et al., 2007; Chauhan et al., 2017). The retreat of glaciers, decreased snowfall, and faster snowmelt driven by rising temperatures have contributed to the degradation of habitats for alpine medicinal plants such as *Neopicrorhiza scrophulariiflora* (Shrestha & Jha, 2009) and *Ophiocordyceps sinensis* (Shrestha & Bawa, 2015).

Figure 6. Lower-Barun Glacial Lake (4450 m asl) is one of the rapidly expanding glacial lakes since its formation in early 1970s (Photo credit: Sudeep Thakuri, 2020)

Changes in precipitation patterns, with some areas experiencing more frequent and severe droughts, while others experience increased flooding are clear evidence of climate warming. These changes in water availability have a significant impact on freshwater ecosystems, altering hydrology and affecting the abundance and distribution of aquatic species (Bhattarai & Pant, 2016). Rising temperatures can also affect freshwater ecosystems, with warmer water temperatures affecting the growth, reproduction, and survival of aquatic species. In particular, some cold-water species, such as trout, are especially susceptible to these changes. Climate change can also impact water quality, with increased temperatures and changes in precipitation patterns leading to altered nutrient and sediment loads, as well as changes in pH levels. These changes can impact the quality of aquatic habitat, and may have knock-on effects on the overall health of freshwater ecosystems (Adhikari & Neupane, 2019). Climate change is intensifying the frequency and severity of extreme weather events, such as floods, landslides, and avalanches (Sudmeier-Rieux et al., 2012; Thakuri et al., 2020; Wijaya et al., 2023). These events can have significant impacts on freshwater ecosystems. For instance, major floods can modify channel morphology and sediment deposition, which may result in changes to habitats and the abundance of aquatic species (Giri et al., 2018).

This scenario of climate change impacts illustrates the vulnerability of Nepal's freshwater ecosystems to climate change and highlights the need for effective management strategies and adaptive measures to minimize these impacts and ensure the long-term sustainability of these crucial systems. Multiple studies have emphasized the importance of sustainable water resource management, such as wetland restoration and the adoption of integrated water resource management, to address the challenges posed by climate change.

Forest and biodiversity

Forest cover

Climate change is causing changes in forest cover in Nepal, with some forests shifting to higher elevations, while others are being replaced by non-forest vegetation (Chaudhary et al., 2017). Forest cover declined by 1.4% y^{-1} from 1995 to 2010, due to factors such as deforestation, forest degradation, and climate change (GoN, 2016). Yet, in recent years forest area has been increasing significantly.

Phenology

Changes in temperature and precipitation have affected the phenology of plants. Multiple studies have provided evidence that increasing temperatures lead to alterations in plant phenology (Scheffers et al., 2016). The timing of flowering in plants is significantly influenced by the onset and retreat of snowfall, as noted by Inouye & Wielgolaski (2003) and Kudo & Suzuki (1999). For example, the early flowering patterns observed in *Aconitum heterophyllum* may be attributed to warmer winter conditions, as evidenced by an average advancement of flowering time by 19-27 days with a 1°C increase in mean winter temperature.

In a study conducted by Lamsal et al. (2017), it was discovered that the flowering time of *Rhododendro*n *arboreum* in the central sub-alpine middle mountains of Nepal advanced by 2-3 weeks, whereas in the western sub-alpine middle mountains, it was delayed by 3-6 weeks. Additionally, the researchers noted an upslope migration of various species, such as *Betula utilis*, *Juniperus indica*, *Rhododendro*n sp., *Berberis* sp., and *Alnus nepalensis*, in the central and western sub-alpine middle mountains.

Phenological changes in three specialized perennial herbaceous alpine flora due to rising temperatures. They observed a delay in flowering time for *Roscoea alpina* and *Roscoea capitata* by 8-30 days, while *R. purpurea* exhibited early flowering by 22 days (Mohandass et al. (2015).

Invasion

Climate change is promoting the spread of non-native species in Nepal, which are negatively affecting native species and ecosystems. One example is the rapid spread of the invasive weed *Mikania micrantha*, which is diminishing the biodiversity of forest ecosystems (Sharma et al., 2018). According to Shrestha et al. (2015), the expansion of invasive species in the high-altitude regions of Nepal is anticipated due to the increasing climatic suitability. The study suggests that *Parthenium hysterophorus* would experience significant growth in the high-altitude areas if the temperature rises by +3°C. Additionally, Rangwala & Miller (2012) discovered that future warming is projected to intensify with altitude, leading to the upward movement and colonization of the invasive species *Ageratina adenophora* in the temperate and sub-alpine forests of the mid-hills and middle mountains in central Nepal. This invasion poses a significant threat to the habitat of endangered fauna such as *Ailurus fulgens* and *Moschus chrysogaster*. Moreover, Bourdôt et al. (2012) predicted that *Nassella neesiana*, a weed typically found in temperate grasslands, could spread to Nepal and disrupt pasture and grassland biodiversity by outcompeting native plants in middle mountain ecosystems.

Vegetation shifting

The tree line shifting has been evident in the Nepal Himalaya (Fig. 7). Gupta (2010) conducted a study in the Gorkha, Mustang, and Manang areas of the western Himalayan belt of Nepal and predicted that a temperature increases of 1°C would lead to an upward shifting of the tree line by approximately 150 m. Similarly, Suwal (2010) studied the upward shift of the tree line of *Abies spectabilis* in the Manaslu region of central Nepal. The research found that the tree line had moved higher in the Manaslu Conservation Area due to climate change, reaching an altitude of 3841 m by 2007, with a shift rate of 34.29 m per decade.

In a study by Gaire et al. (2014) across Nepal, which focused on tree ring analysis, an upward shift was observed in the tree line of *Abies spectabilis* at a rate of 2.61 m y^{-1} since 1850 AD was observed. However, the upper distribution limit of *Betula utilis* remained relatively stable in recent decades. Chhetri and Cairns (2015) also observed the migration of the alpine tree *Abies spectabilis* upslope at a rate ranging from 0.17 to 2.6 m y^{-1} in central Nepal. Pauli (1994) calculated that for every 100 m increase in elevation, a temperature rises of 0.5°C could theoretically result in an 8-10 m shift in vegetation belts per decade. Furthermore, Chettri et al. (2009) estimated that, considering the current rate of warming in the eastern Himalaya, which is expected to increase with altitude, the altitudinal shift of species such as *Abies spectabilis* and *Betula utilis* could range from 20-80 m per decade as they move to higher altitudes.

Figure 7: High-altitude vegetation that are migrating upward in Barun valley (Photo credit: Sudeep Thakuri, 2020).

Species distribution and composition

Climate change is impacting wildlife in Nepal, as changes in temperature and precipitation patterns influence the distribution, abundance, and behavior of various species. For instance, certain bird species are moving their breeding ranges to higher elevations, while some mammals are adjusting their activity patterns to evade high temperatures (Subedi et al., 2017). Gautam et al. (2018) assessed the impacts of climate change on the distribution of three bird species in the Langtang National Park and found alterations in the geographical distribution of these bird species due to climate change, with some populations declining and others expanding their range. Ale et al. (2019) assessed the impacts of climate change on snow leopard populations in Nepal. The study found that climate change is affecting the snow leopard's habitat, as warming temperatures are causing glaciers to melt and snow cover to diminish. This is leading to changes in prey populations, which in turn is affecting snow leopard survival. These studies provide evidence that climate change is exerting notable effects on the wildlife in Nepal, causing changes in their distribution, behavior, and ultimately their survival. These impacts have significant implications for the overall ecological balance of Nepal's natural systems and the well-being of local communities that depend on these ecosystems for their livelihoods and cultural heritage.

Forest fire risk

Climate change is increasing the risk of forest fires in Nepal, due to factors such as warmer temperatures, drier conditions, and more frequent droughts. Forest fires can have significant impacts on forest ecosystems, including loss of biodiversity, carbon emissions, and soil erosion (GoN, 2016). A study on the wildfire risk in Chitwan-Annapurna Landscape showed that increasing temperatures, decreasing precipitation, and changes in wind patterns are contributing to an elevated risk of forest fires in the region (Sharma et al., 2018). Climate change is contributing to an increased risk of forest fires in Nepal, with implications for both the ecological and human systems. Effective forest management practices and strategies to implement measures to reduce the effects on forest ecosystems will be essential due to climate change in addressing this risk and promoting the sustainability of Nepal's natural systems.

Conclusion

Nepal is witnessing profound effects of climate change on its environment, economy, and society. Rising temperatures have led to glacier melt, changes in precipitation patterns, and a higher frequency and intensity of climate and water-related disasters, along with a loss of biodiversity. This has resulted in droughts, floods, landslides, and other natural disasters that have affected the agricultural sector, energy production, and infrastructure development. In addition, the emergence of invasive species as a consequence of climate change has brought detrimental effects on biodiversity and forest ecosystems. This situation is particularly critical in Nepal's mountainous regions, which hold significant natural resources and cultural significance. As a result, it is essential for the government to adopt proactive measures and implement effective strategies to mitigate and adapt to climate change. These efforts are vital to reducing the negative effects on Nepal's environment, economy, and society.

The climatic trends observed in Nepal's high-altitude ecosystems are reshaping biodiversity patterns and threatening vital ecosystem services. Rising temperatures, altered precipitation, and shifting seasons are accelerating the vulnerability of these fragile environments, with significant implications for both local communities and global biodiversity. Immediate, science-based interventions and adaptive conservation strategies are crucial to mitigate these impacts. Moreover, integrating climate resilience into policy and development planning, alongside continued research and monitoring, is essential for safeguarding the ecological integrity of these high-altitude ecosystems. Preserving these regions is not only vital for Nepal, but for the broader health of the planet.

Conflict of Interest

The authors state that there are no conflicts of interest related to this publication.

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Noise Pollution and Its Impact on Health in Kathmandu Valley, Nepal: A Case Study

Puja Puri[1], Mahesh Prasad Awasthi[2], Aashish Chapagain[1], Samichhya Poudel[1], Samiksha Pokhrel[1], Uttam Sagar Shrestha[3], Ramesh Raj Pant[1*]

[1]Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Nepal
[2]Faculty of Science and Technology, Central Campus, Far Western University, Mahendranagar, Kanchanpur, Nepal
[3]Padmakanya Multiple Campus, Bagbazar, Institute of Science and Technology, Tribhuvan University, Nepal
*Correspondence: rpant@cdes.edu.np

Abstract

Noise is an unwanted and unpleasant sound that occurs in the wrong place at the wrong time. It can impair hearing, increase stress levels and reduce concentration and work efficiency. In recent years, noise pollution has been rising rapidly. This study aims to assess the extent of noise pollution and its health effects on residents of the Pepsicola area in Kathmandu Valley. A descriptive cross-sectional study design was employed, using a non-probability sampling technique. Sound pressure levels were measured during peak hours using a sound level meter (SL-4010), and data were collected through semi-structured questionnaires administered to 50 respondents across residential, commercial, industrial, traffic and school zones. The findings revealed that average noise levels were highest in industrial areas and lowest in residential zones during both morning and evening periods. Over 60% of respondents demonstrated limited awareness of noise pollution, while 70% reported experiencing significant health effects, including headaches, hypertension and emotional instability. Some of the recorded noise levels exceeded the limits set by both the World Health Organization (WHO) and the Government of Nepal (GoN), indicating a serious public health concern. To mitigate these effects, the study recommends measures such as roadside tree plantations, stricter enforcement of existing noise regulations and the implementation of effective noise reduction strategies.

Keywords: *Noise level, Health effects, Mitigation strategies, Public awareness, Pepsicola*

Introduction

Noise pollution has now become a significant environmental issue. Any unwanted or excessive sound compromises the natural acoustic environment (Miller, 1998). World Health Organization (WHO) declared noise a pollutant in 1992 (Helgeson & Dread, 2019). As urbanization progresses and the extension of transportation networks continues, the health effects associated with noise pollution increase (Hsu et al., 2012). According to the WHO exposure to noise above 70 dBA could pose a danger to health as a contributor to conditions such as cardiovascular illness, insomnia and cognitive impairment. Reportedly, over 18% of the urban UK population is exposed to harmful noise levels, translating to thousands of premature deaths annually across Europe due to noise-related health problems (Day, 2022).

Noise pollution is not merely a nuisance; at times, it may even have physiological and psychological effects(Muhammad Anees et al., 2017). It leads to increased stress levels due to chronic exposure and raises blood pressure, which lowers quality of life (Anomohanran, 2013). Children are mostly vulnerable to harmful effects of noise in that exposure to environmental noise significantly constrains the process of memory formation in children concerning the weak attention span (Costa et al., 2013). Understanding and avoiding noise pollution helps to promote healthy urban environments. The assessment of noise pollution involves systematic methods of measuring sound levels within different environments wherein tools like sound level meters (Britannica, 2020) and noise mapping techniques are often employed. Sounds produce two characters i.e. frequency and amplitude indicating sound loudness in terms of decibels (dB)

(Morfey, 2021). The decibel scale is logarithmic, meaning each 10 dB increase represents a tenfold increase in sound intensity. To put this into perspective, a sound at 60 dB is one million times more intense than a barely audible sound at 0 dB. This explains why even small increases in decibel levels can have a big impact on noise perception and potential hearing damage (Costa et al., 2013).

Noise pollution has become an important public health concern worldwide; WHO announced that noise exposure above 70 dBA can harm human health severely, causing cardiovascular disease and even cognitive impairment (Clark & Paunovic, 2018). In Nepal, urban centers such as Kathmandu are increasingly faced with noise pollution problems as urbanization advances at a fast rate and traffic grows, notwithstanding a set of regulations put in place to fix noise limits per zone (Pun & Gurung, 2023). At a local level, there are rising noise levels in the Pepsicola area of the Kathmandu Valley because of mixed land use and infrastructure development extending in the area. Noise pollution is a major environmental issue in urban areas, and it's becoming increasingly problematic in rapidly developing cities like the Pepsicola area of Kathmandu Valley. One of the primary sources of urban noise pollution is traffic (Rayamajhi, 2017). To manage noise pollution, Nepal has set standard permissible sound levels for different zones as of the year 2069 B.S. For instance, industrial zones are allowed up to 75 dB during the day and 70 dB at night. In contrast, urban residential areas have stricter limits, with thresholds of 55 dB during the day and 45 dB at night. These regulations aim to protect public health and maintain a livable environment, especially in rapidly urbanizing areas like Pepsicola in Kathmandu Valley (Noise Level Standard of Nepal, 2069). Maintenance levels for silent zones are expected to be 50 dB during the day and 40 dB at night time (Pun & Gurung, 2023).

While Nepal has implemented certain noise control measures such as 'No Horn' zones and area-specific noise limits under the National Sound Quality Standard of 2069 B.S., these regulations are often limited in scope and enforcement (Bhattarai, 2014). For example, although the Kathmandu Valley was declared a no-horn zone in 2017, studies show that compliance and monitoring remain weak. Therefore, comprehensive and enforceable guidelines for noise pollution prevention and control are still lacking, especially in rapidly urbanizing areas like Pepsicola. This study aims to investigate the actual noise levels in the ambient air of the Pepsicola area in Kathmandu Valley, with the goal of contributing to the formulation of more effective noise pollution guidelines. Pepsicola represents a growing concern due to rapid urbanization and increasing traffic, where residential, commercial and industrial land uses coexist. Thus, the main objectives of this study are to measure ambient noise levels, identify primary sources of noise, assess potential health impacts and recommend mitigation strategies. These efforts are intended to enhance understanding of noise pollution and support the development of public health policies in the Kathmandu Valley.

Materials and Methods

Study area

Kathmandu, the capital city of Nepal, spans an area of 395 km² and is surrounded by several municipalities, including Bhaktapur to the east, Kirtipur to the west and Lalitpur to the south. To the north, it is bordered by Nagarjun, Tokha, Tarakeshwor, Budhanilkantha, Gokarneshwor, and Kageshwori Manohara. Due to rapid urbanization and industrial development, Kathmandu faces significant noise pollution, which adversely affects both human and animal health. With an estimated population of 1,471,867 in 2021, the city experiences frequent traffic congestion and occupational noise, particularly during the daytime. Pepsicola, located in Ward No. 32 of Kathmandu, was selected as a study area for assessing noise pollution using a Sound Level Meter. This urban neighborhood lies at the beginning of Bhaktapur Road in the eastern part of Kathmandu, near the Purano Sinamangal Temple and Tribhuvan International Airport. The area derives its name from the nearby Pepsicola factory and spans approximately 0.36 kilometers. Given the area's proximity to major roads and industrial zones, there is a pressing need to investigate noise pollution levels and their health impacts on local residents.

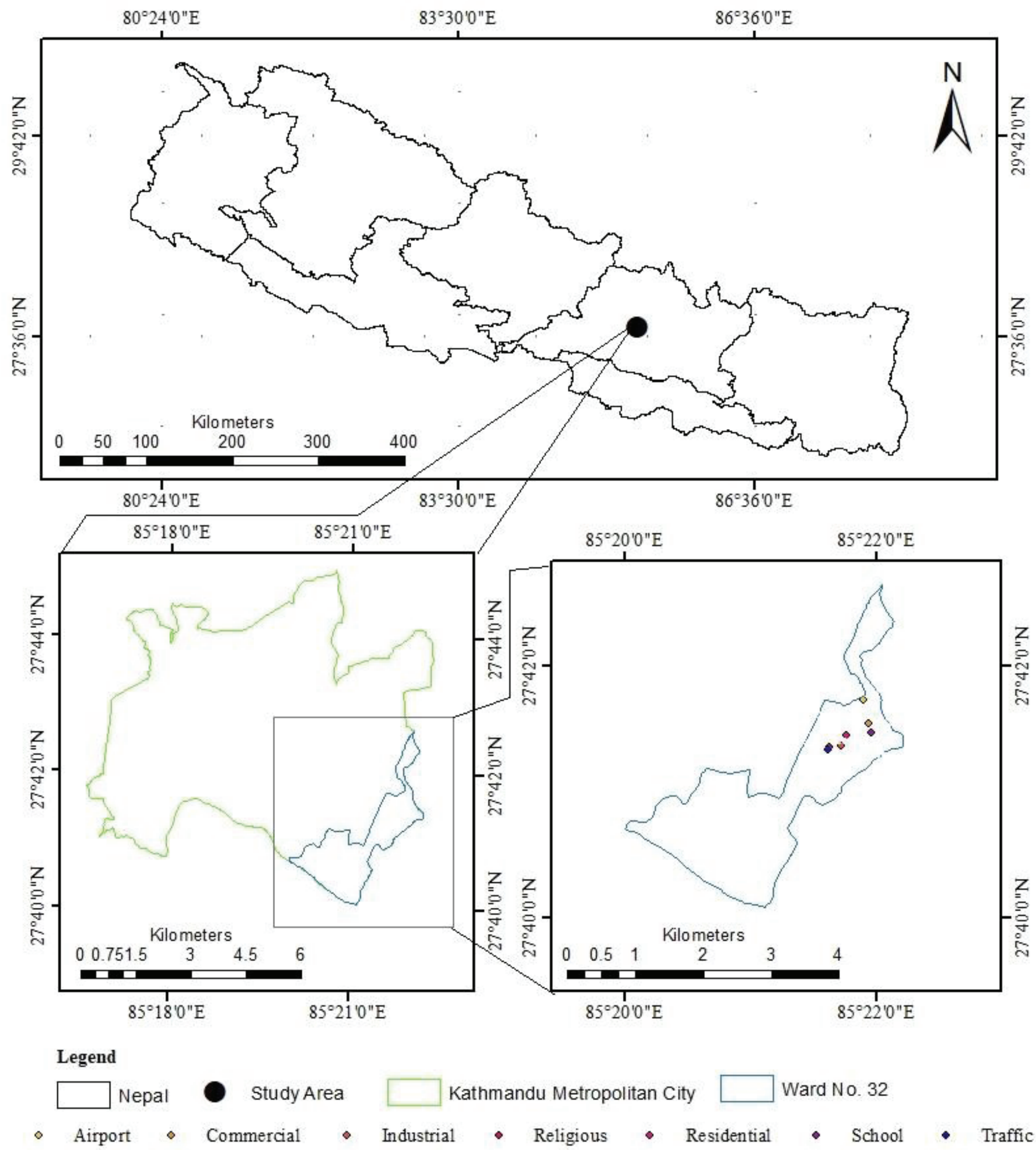

Figure 1: Study Area Map

Sampling Methods

Both primary and secondary data collection methods were employed in this study. The primary data were gathered through field observations, while the secondary data were obtained from published and unpublished journals, reports and official documents.

For the primary data collection, noise levels were measured across seven distinct zones: residential, commercial, industrial, religious, traffic, airport and school areas. A Sound Level Meter (Model SL-4010) was used to monitor the sound pressure levels in these zones. The measurement settings were categorized into three ranges: Range 1: Residential areas; Range 2: Commercial, school, and religious areas; Range 3: Industrial, traffic, and airport areas.

Measurements were conducted from October 13 to November 9, 2022, during two daily time slots: 9:00

to 10:00 AM and 4:00 to 5:00 PM. At each sampling point, sound levels were recorded for one hour, with readings taken every minute and a 2-minute interval between each reading. The sound level meter was positioned at a height of 1.5 meters above ground level. All measurements were taken under calm weather conditions, with no rainfall and typical traffic flow. In addition to field measurements, a questionnaire survey was conducted to assess public perception of noise pollution and its health impacts. A total of 50 respondents from the study area participated in the survey over the course of one month. The survey collected data on individual's experiences and health symptoms related to noise exposure. After data collection, the maximum and minimum noise levels were identified and compared with the standard noise level limits set by the Government of Nepal.

Data Analysis and Interpretation

The primary tool used for data collection was a Sound Level Meter, which measured environmental noise levels across various zones. In addition, a semi-structured questionnaire survey was conducted to gather information on health issues experienced by individuals due to their working environment and exposure to noise pollution. The collected data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 25. Various graphs and charts were plotted to visually represent the variables and findings. The responses from the questionnaire were evaluated to determine the knowledge level of participants regarding noise pollution and its health effects. These scores were then interpreted and categorized using a Percentage-Based Grading System.

Formula used was:

$$L_{eq} = 10\mathbf{log}_{10}\left(\frac{N}{1}\sum_{\boldsymbol{i=1}}^{\boldsymbol{N}}\mathbf{10}\,\frac{Li}{10}\right)$$

Results and Discussion

Noise level at different sites in the morning and evening time

Table 1 presents a statistical summary of noise levels recorded during the morning across seven distinct zones. Among these, residential areas had the lowest average noise level at 47.3 dB, ranging from 43.1 to 52.8 dB. In contrast, industrial zones were the loudest and most consistent, with a mean of 93.99 dB, a range of 91.1 to 98.1 dB and the lowest standard deviation of 2.1, indicating stable noise levels. While residential zones remained relatively quiet, the school zone showed notable variability, suggesting a dynamic noise environment likely influenced by student activity. Traffic and airport zones had comparable noise levels, whereas religious areas maintained moderate noise levels within a narrow range (Table 1 and Figure 2).

Similarly, the evening data in Table 1 shows that residential areas continued to be the quietest, with a mean noise level of 46.3 dB (range: 40.6 to 51.6 dB) and a low variability (standard deviation: 2.9). On the other hand, industrial zones recorded the highest evening noise levels, with a mean of 97.3 dB (range: 93.1 to 103.2 dB) and a moderate standard deviation of 3. Religious and airport zones had similar evening noise characteristics, with mean values of 69 dB and 77 dB, and low standard deviations of 2.6 and 2.7, respectively. The school zone again showed the widest variability, with a standard deviation of 6, reflecting fluctuations in noise levels due to student presence during peak hours. Thus, the industrial areas consistently recorded the highest noise levels, followed by airport and traffic zones, while residential and religious zones remained relatively quieter throughout the day.

In the study carried out on Dindigul-Bangalore road (NH-209) by Subramani, Kavitha and Sivaraj (2012), it was found that traffic noise from highways creates problems for surrounding areas, especially when there are high traffic volumes and high speeds but in this study the industrial area shows high noise level, this variations could be due to the different set of environmental conditions (Table 1, Fig. 3).

Table 1: Noise level in different sites

Time	Morning				Evening			
Area	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
Residential area	43.1	52.8	47.3	3.0	40.6	51.6	46.3	2.9
Commercial area	60.5	71.3	66.6	2.8	62.1	72.6	65.9	3.2
Industrial area	91.1	98.1	93.9	2.1	93.1	103.2	97.3	3
Religious area	64.9	73.1	68.2	2.4	65.3	74.1	69	2.6
Traffic area	67.1	81.3	74.2	4	67.7	80.2	72.8	3.7
Airport area	72.3	86.8	76.9	4	72.8	83	77	2.7
School area	63	82.4	68.8	5.3	62.1	81.2	68.8	6

Source: Field Survey, 2022

The recorded data from different areas at different times, with their minimum, maximum, mean, median, and standard deviation, have been tabulated in Table 1.

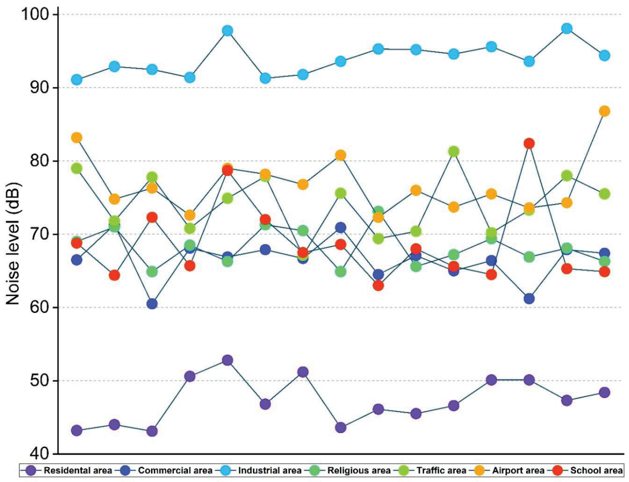

Figure 2: Noise level in different sites at morning time

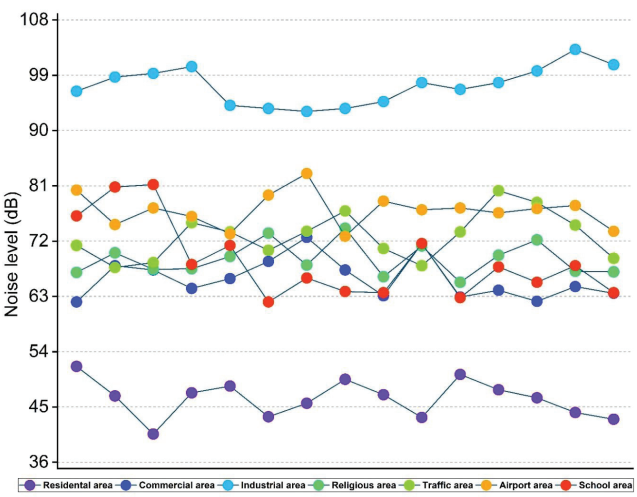

Figure 3: Noise level in different sites at evening time

Comparative data of Noise level during morning and evening time

The comparative data of the noise level during morning and evening time of different zones is presented in Figure 4 and Figure 5.

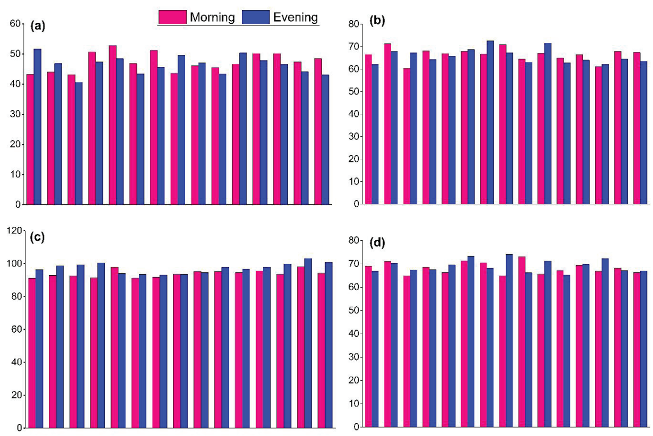

Figure 4: Noise level during morning time of different zones

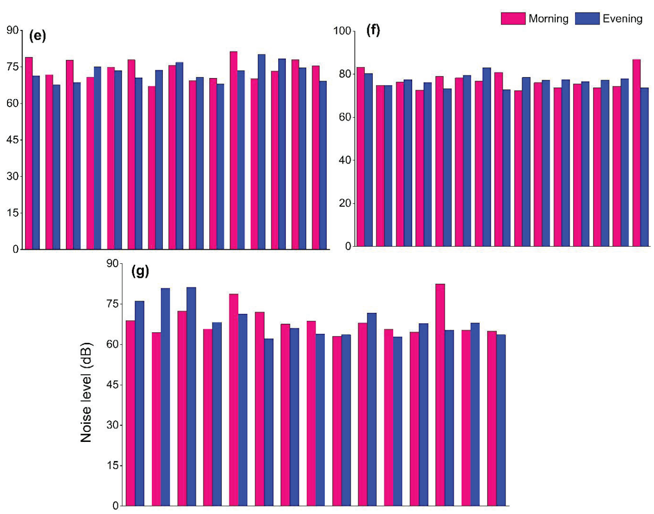

Figure 5: Noise level during evening time of different zones (Field Survey, 2022)

Figure 4 illustrates the noise level status during the morning period, highlighting variations across different zones. In contrast, Figure 5 shows that the sound levels in residential areas during the evening are slightly above the average, indicating relatively low noise exposure compared to other zones. For instance, sound levels in residential areas during the evening showed a slight decline, with the mean dropping from 47.3 dB to 46.3 dB, and the maximum value decreasing from 52.8 dB to 51.6 dB. Additionally, there was a minor reduction in variability, as indicated by the standard deviation decreasing from 3.0 to 2.9. According to the limit set by the WHO standards, there should be a noise level of not more than 50 dB at a school site, 55 dB at a residential site, 65dB at a commercial site, 70 dB at an industrial site (GoN, 2069). However, the observed data were above the limit set by WHO except for residential areas whose highest dB was 52.8dB other than that all other sites have crossed the limit and directly or indirectly affected the health of all living beings. Noise levels at industrial sites in the evening increase tremendously, (mean of 93.9 dB in the morning to over 100 dB during the evening). With this, the standard deviation also increases from 2.1 to 3.0 showing more variation in the evening recordings. Consequently, religious areas show a slight increase in the mean value from 68.2 dB to 69 dB, similar medians and a slight increase in standard deviation (2.4 to 2.6), which indicates more or less uniform levels of noise at any time of the day.

Traffic areas showed average noise reduction from 74.2 dB to 72.8 dB from evening to morning. The maximum and the standard deviation thus show a decline, as this all comes with reduced variation during the night. Overall, while some areas show lesser noise and variability in the evenings, others such as industrial and religious areas show increased noise due to the different activity patterns across these zones. Likewise, the study carried out by Swain and Goswami, (2018) explicitly revealed that the noise levels are more than the permissible limit in all the investigated sites in Bhubaneswar and Puri, Odisha in India. Moreover, it depicts that the transportation sector is one of the major contributors to noise in this city and the average noise level at all sites was found to be above the prescribed limits. In this study, the industrial area consistently recorded the highest noise levels during both morning and evening periods. These levels were found to exceed the permissible limits set by the Government of Nepal, aligning with findings from previous research conducted by other scholars (Chauhan et al. 2021; Swain & Goswami, 2018).

Table 2: level of knowledge on noise pollution among respondents (n=50)

Variables	**Yes**		**No**				**Don't know**	
	Frequency(n)	(%)	Frequency(n)	(%)			Frequency(n)	(%)
Do you know about the "Noise"?	46	93	2	4			2	4
Do you consider "Noise" as environmental pollution	11	22	31	62			8	16
Do you know that Noise affects human health?	45	90	3	6			2	4
How many hours a day do you spend in this setting?	>3hrs		3-5hrs		>5hrs		Don't know	
	Frequency(n)	(%)	Frequency(n)	(%)	Frequency(n)	(%)	Frequency(n)	(%)
	5	10	15	30	20	40	10	20
What kind of noise do you perceive most in your area?	Yes				No			
	Frequency(n)		(%)		Frequency(n)		(%)	
(a) Traffic Noise	50							
(b) Airplane Noise	20		40		30		60	
(c) Construction Noise	15		30		35		70	
(d) Religious Noise (Bhajan/Bell)					50		100	
(e) Industrial Noise	14		28		36		72	
(f) School Noise	40		80		10		20	
(g) Hospital Noise					50		100	
(h) Crowd	35		70		15		30	
(i) Neighborhoods Noise	10		20		40		80	

Source: Field Survey, 2022

Knowledge regarding the pollution level

The perception of knowledge on the effect of noise level on health collected from 50 residents is presented in Table 3.

Table 3 shows that almost all 92% of the respondents know about "Noise". More than half of the respondents 58% did not know noise caused environmental pollution. Most of the respondents (90%) know that noise causes health effects in humans. Most of the respondents 40% spend more than 5 hours in their particular setting. The majority of the respondents from the traffic area and school area perceived excessive noise at 100% and 80%, respectively. This reveals that more than half of the respondents 60% had inadequate knowledge level about noise pollution, however, they knew about its source. This indicates that there is a lack of awareness among local people residing in the Pepsicola area.

Table 3: Level of Knowledge on Noise Pollution (n=50)

Knowledge Level	Frequency(n)	Percentage (%)
Adequate	20	40
Inadequate	30	60

Table 4 shows that more than half of the respondents (60%) had inadequate knowledge about noise pollution whereas (40%) had adequate knowledge (Table 4).

Health effect of noise pollution

The health effect of noise pollution collected from fifty households is presented in Table 5.

Table 5 shows that the majority of the respondents 90% were free from cardiovascular disease from noise pollution. Most of the respondents 70% were at a medium level of emotional instability. Likewise, 60% of the respondents felt high-level effects from noise and could not hear properly until another person spoke loudly. More than half of the respondents 60% and 80% felt a high level of effect of noise that caused them hypertension and headache, respectively. As in the study of Rahman et al. (2020), 94% of respondents reported headache, 76% sleeplessness, 74% hypertension, 74% physiological stress, 64% elevated blood pressure levels, and 60% dizziness due to noise. This showed that noise is a crucial factor in changing the state of living life. In Table 5 majority of the respondents (60%) were irritated at a medium level and almost all of them were found to suffer from gastrointestinal/stomach problems. Half of the respondents (50%) felt speech disturbance at a medium level. All the respondents felt negligible levels of sleep disturbance and feelings of vomiting. More than half of the respondents felt medium levels of chest pain 60% and dizziness 70%, respectively.

In comparison to the study of Muhammad et al. (2018), it was found that a huge number of the

Table 4: Health effects of noise pollution among respondents (n=50)

Statements	No		High		Medium		Low		Negligible	
	N	%	N	%	N	%	N	%	N	%
Cardiovascular disease	45	90	5	10	-	-	-	-	-	-
Emotional instability	10	20	-	-	35	70	5	10	-	-
Couldn't hear properly until other speaks loudly	10	20	30	60	10	20			-	-
Gets often tired working in noisy areas	-	-	25	50	15	30	10	20	-	-
Hypertension	15	30	30	60	-	-	5	10	-	-
Often headache	-	-	40	80	10	20	-	-	-	-
Gets irritated easily	10	20	10	20	30	60	-	-	-	-
Gastrointestinal/ stomach problem	-	-	50	100	-	-	-	-	-	-
Speech disturbance	15	30	10	20	25	50	-	-	-	-
Sleep disturbance	-	-	-	-	-	-	-	-	50	100
Chest pain	-	-	5	10	30	60	-	-	15	30
Feeling of Vomiting	-	-	-	-	-	-	-	-	50	100
Feeling of Dizziness	15	30	-	-	35	70	-	-	-	-
Make difficulties in concentration	15	30	10	20	-	-	-	-	25	50

Source; Field survey, 2022

population has apparent problems of disturbed sleep, annoyance, low outcomes in the performance of the daily life of industrial persons and an increase of hypertension with another certain cardiovascular disease. Likewise, results from the study conducted by Agarwal and Swami (2011) reported that road traffic was the major source of noise in the area. Results of a health survey reported that about 52% of subjects were suffering from frequent irritation, 46% had hypertension, 48.6% reported difficulties in sleep due to traffic noise and females were more sensitive to noise-related health problems. These findings are in line with similar studies in urban India and other South Asian cities, where industrial and transportation sectors are major contributors to excessive noise pollution (Sahu et al., 2020; Pun & Gurung, 2023).

Table 5: Level of respondents view on effects of health from noise pollution (n=50)

Health effect Score	Frequency(n)	Percentage (%)
Maximum	35	70
Minimum	15	30

Table 6 indicates that a significant majority of respondents (70%) reported experiencing substantial health effects due to noise pollution. This suggests that noise pollution is a major concern for residents, particularly in the Pepsicola area of the Kathmandu Valley. Although Nepal has implemented certain noise control measures such as designated no-horn zones and area-specific noise limits, the absence of comprehensive and consistently enforced regulations likely contributes to the frequent surpassing of safe noise thresholds (Pun & Gurung, 2023).

Conclusion

This study underscores that noise pollution in the Pepsicola area of Kathmandu frequently exceeds both national and international permissible limits, particularly in industrial zones and high-traffic corridors. Residents working in or living near these areas reported a range of health issues most notably headaches, gastrointestinal disturbances, hypertension, and irritability attributed to prolonged exposure to elevated noise levels. Despite the severity of the issue, public awareness remains low, with a majority of respondents lacking sufficient knowledge about noise pollution and its health implications.

These findings highlight the urgent need for targeted public awareness campaigns, stricter enforcement of existing noise control regulations, and the implementation of mitigation strategies such as urban zoning, installation of sound barriers, and roadside tree plantations. However, the study is limited by its data collection scope, which was restricted to peak hours due to COVID-19 constraints, preventing comprehensive all-day monitoring. Future research should incorporate long-term noise surveillance, individual exposure assessments, and more detailed health evaluations to better quantify risks and guide effective policy interventions.

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Assessment of Heavy Metal Concentration in Soil and Water from Mechanic Sites in Makurdi, Benue State, Nigeria

Idakwo Abutu Mark-Victor, Tembe T. Emmanuel, Okoh Thomas
Department of Environmental Sustainability, Joseph Sarwuan Tarka University,
Makurdi, Nigeria
*Correspondence: idakwo.abutu@uam.edu.ng

Abstract

This study assessed heavy metal concentrations and physicochemical properties in soil and water samples from mechanic workshops in Apir and North Bank, Makurdi, Nigeria. sixteen soils, sixteen water samples were collected using a systematic random sampling design, along with control samples from uncontaminated sites. Soil samples were collected from depth of 15 cm using a hand auger and stored in labeled polyethylene bags, while water samples were collected in clean plastic bottles and taken to the laboratory. The physicochemical properties analyzed included pH, moisture content, cation exchange capacity (CEC), electrical conductivity (EC), and total dissolved solids (TDS), measured using standard laboratory procedures. Heavy metal concentrations of manganese (Mn), lead (Pb), iron (Fe), and chromium (Cr) were determined using atomic absorption spectrophotometry (AAS) after acid digestion. The results showed that North Bank soils had higher manganese levels (1.24 mg/kg) compared to Apir (0.28 mg/kg), while Apir exhibited elevated concentrations of lead (3.14 mg/kg) and chromium (1.04 mg/kg) compared to North Bank (Pb: 2.78 mg/kg, Cr: 0.57 mg/kg). However, all heavy metal concentrations were below the NESREA (National Environmental Standards and Regulations Enforcement Agency) permissible limits. Soil pH values were 7.2 for North Bank and 6.9 for Apir, both within the acceptable NESREA range (6.5–8.5). Moisture content and CEC were higher in North Bank and Apir, respectively. Water samples contained no detectable levels of manganese, lead, or chromium, and their physicochemical properties, including pH, EC, and TDS, were within safe limits. The findings suggest that soil contamination remains within regulatory thresholds, necessitating continuous monitoring and improved waste management practices.

Keywords: *Contamination, Electrical conductivity, Systematic, Thresholds*

Introduction

The improper disposal of spent motor oil at mechanic sites is a significant environmental issue, especially in urban areas like Makurdi, Nigeria, where mechanic workshops are prevalent. Spent motor oil contains harmful substances such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals, including lead (Pb), iron (Fe), chromium (Cr), and other toxic elements. These substances, when disposed of improperly, can seep into the soil and water systems, leading to contamination that disrupts the natural balance of the environment (Okobia et al., 2024; Nwite & Alu, 2015). The infiltration of spent motor oil into soil alters its physicochemical properties, including an increase in soil acidity, which significantly reduces its fertility and makes it less suitable for agricultural or ecological purposes (Ogugbue et al., 2017; Nwite & Alu, 2015). Additionally, the contamination of soil with heavy metals can interfere with nutrient availability, further degrading soil quality and diminishing its ability to support plant growth (Kabata-Pendias & Pendias, 2011).

Heavy metals, such as Pb, Cr, and Fe, are of particular concern due to their toxicity and persistence in the environment. These metals can accumulate in the soil, leading to long-term contamination that can affect plant and microbial life (Alloway, 2013). The immobilization of essential nutrients by heavy metals, along with the reduction in microbial diversity and activity, impairs soil health and its natural processes, such as organic matter decomposition and nutrient cycling (Jung et al., 2016). Soil microbial populations, which are crucial for maintaining soil fertility, are also severely impacted by the presence of these toxic substances. Studies have shown that in areas contaminated with spent motor oil, the abundance and diversity of microorganisms decrease, with only a few resilient species surviving, while others, essential for bioremediation and soil regeneration, are eliminated (Okobia et al., 2024; Onwujekwe et al., 2022).

Moreover, the contamination of water sources with heavy metals and other pollutants from spent motor oil poses significant health risks to humans and wildlife. Contaminated water can affect communities that rely on local water sources for drinking, irrigation, and other domestic purposes (Mohanty et al., 2013; Onwujekwe et al., 2022). The accumulation of heavy metals in the food chain can lead to serious health conditions, including cancer, liver damage, and neurological disorders (Eze & Orjiakor, 2020). Given the widespread use of mechanic workshops in Makurdi and the improper disposal of spent motor oil in these areas, both soil and water quality are at risk. This highlights the urgent need for effective environmental management strategies, including proper waste disposal methods and the promotion of bioremediation techniques to restore affected sites. The contamination of both soil and water by spent motor oil remains a critical issue that requires further investigation and action to prevent long-term environmental damage and safeguard public health (Ogugbue et al., 2017; Onwujekwe et al., 2022). The aim of this study is to investigate the impact of spent motor oil on soil and water quality in mechanic sites located in Makurdi, Nigeria with the objectives of assessing the basic physical and chemical properties of soil and water and also carrying out heavy metals analysis on the soil and water samples from the mechanic sites while also comparing the level of pollution with NESREA standards.

Materials and Methods

The Study Area

Makurdi, the capital of Benue State in North Central Nigeria, is situated along the Benue River at latitude 7.44°N and longitude 8.32°E, within the Benue valley, and approximately 100 meters above sea level. In 2007, Makurdi had an estimated population of 500,791 and covered an area of about 820 km². The city is characterized by various human activities such as irrigational farming, sand extraction for construction, fishing, market operations, and auto-mechanic sites, which are significant sources of heavy metal pollution (Adamu et al., 2003).

For this study, two sampling sites were chosen within Makurdi: The Kanshio mechanic site at latitude 7.69°N and longitude 8.54°E, located along the Makurdi-Otukpo road opposite the National Open University, known for its extensive automobile repair and maintenance services; and the North Bank Mechanic site at latitude 7.73°N and longitude 8.53°E, recognized for motor body repairs and mechanical and electrical motor services.

Sample Collection

Random sampling techniques were employed to collect both soil and water samples from the 2 different mechanic sites located at Kanshio and North Bank. Soil sample was also collected from a farm land close to the mechanic sites and was used as a control while control for water was taken from well water away from the mechanic sites. A soil auger was used to collect the soil samples at a depth of 15 cm. A total of sixteen soil samples and sixteen water samples were collected to be analyzed. The collected soil samples were placed in a clean polythene bag before being transferred into a well-labelled zip bag and moved to the lab. Water samples were placed in clean labeled water bottles.

Soil Sample Collection and Preparation: Before heading out to the field, all sampling equipment, including soil augers, spades, gloves, and polyethylene bags, were cleaned and sterilized to prevent contamination. The polyethylene bags were labeled with relevant information such as site location, depth, and date of collection to maintain organization. At each site, soil samples were collected from the top 0-15 cm layer using a soil auger. This depth is critical as it is most likely affected by surface contaminants like spent motor oil. A random sampling method was employed to

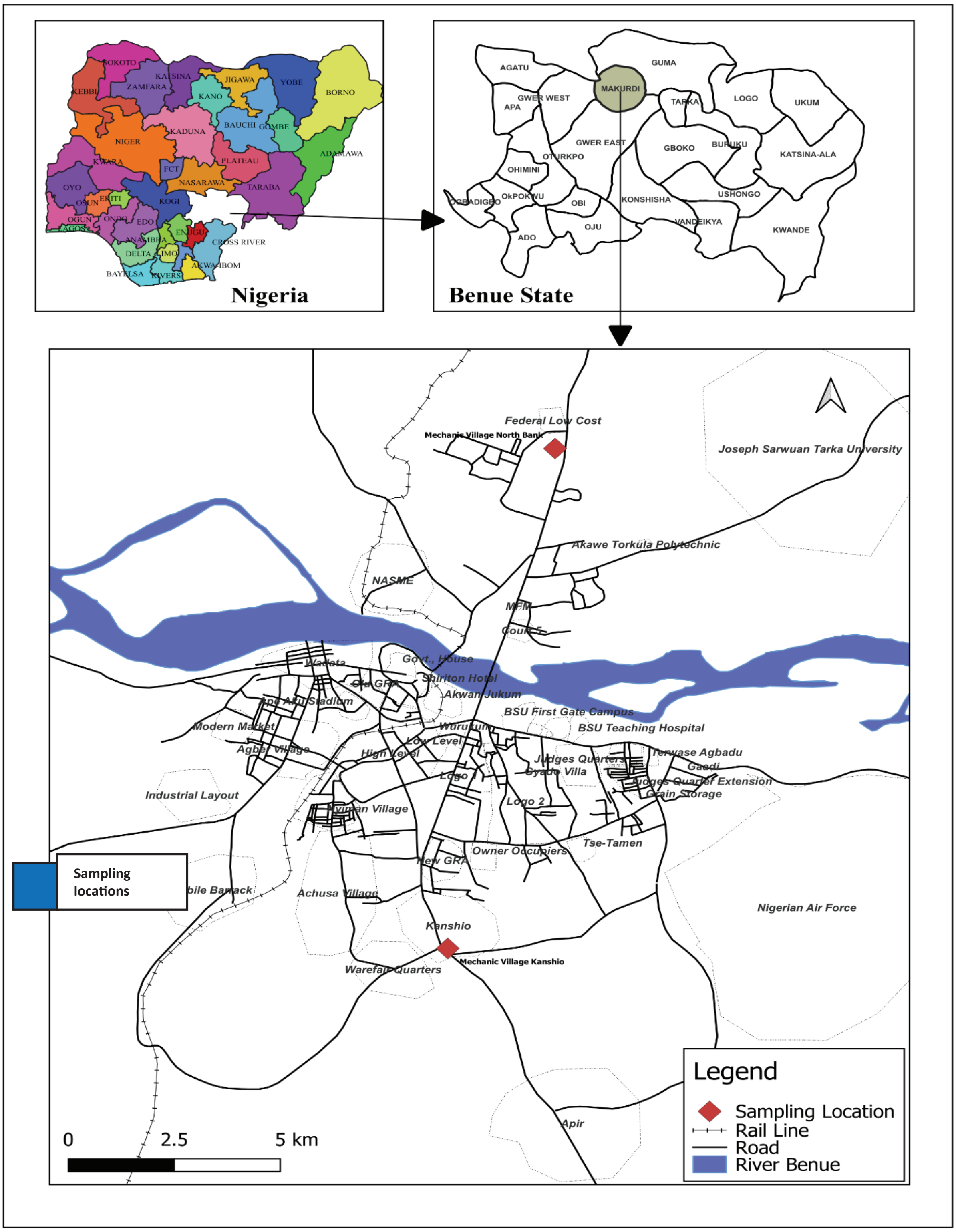

Fig 1: Map of Makurdi showing the Sampling Locations

select specific points within each site, ensuring that the samples were representative. Using the soil auger, it was carefully inserted into the soil to the desired depth, rotated to cut through the soil, and then lifted out to retrieve the sample. Each composite soil sample was placed into its labeled polyethylene bag, which was tightly sealed to maintain the sample's integrity. Upon arrival at the lab, the soil samples were spread on clean trays to air-dry at room temperature, reducing moisture content. After drying, the samples were passed through a 2-mm sieve to remove debris and homogenize them. Thorough mixing of the sieved soil ensured uniformity in the sample. The prepared samples were then stored in labeled containers for subsequent analyses. For physical and chemical analyses, measurements of soil pH, percentage moisture, Cation Exchange Capacity (CEC), particulate nature, Total dissolved solids, organic dissolved oxygen, turbidity, and heavy metals were conducted.

Water Sample Collection and Preparation: Sampling sites were carefully selected based on their proximity to mechanic sites and potential points of oil contamination from groundwater sources. Clean plastic bottles were used for collecting the water samples to avoid contamination. The sampling process involved collecting water from different points within each designated site to ensure a representative sample. Each sample bottle was labeled with the site location, date, and time of collection. Upon arrival at the laboratory, the water samples were subjected to a series of analyses to determine their physical, and chemical properties. Physical parameters such as pH, total dissolved solids, dissolved oxygen, and turbidity were measured using appropriate sensors and meters. The chemical analyses focused on detecting contaminants like heavy metals (manganese, Fe, Pb, Cr).

Laboratory Analysis

Determination of Soil Quality Parameters:

The physiochemical parameters were determined using standard laboratory methods as reported by Gupta and Sinha. (2006).

Determination of soil pH: Weigh 5g of the soil sample, suspend it in 50 mL of distilled water, then put the pH meter and take the pH reading.

Cation Exchange Capacity: A CEC meter is used to take the reading.

Percentage Moisture: Using the oven drying method, the soil sample is collected in a moisture can, and wet weight of the sample is recorded. The soil sample is dried in a hot air oven at 105 ^{0}C until constant weight is obtained and dry weight of the sample is recorded.

$$\text{Moisture content (on weight basis)} = \frac{Wet\ weight - Dry\ weight\ X\ 100}{Dry\ Weight}$$

Particulate Nature: Weigh 100g of the soil in a measuring cylinder, add 100mL of water and 5g of detergent. Shake the mixture rigorously. Allow the mixture to settle to allow the different particles to settle in the order of top to bottom with clay on top, then sand and silt. Measure the entire length of the soil in cm, then also measure the length of the individual clay, sand and silt. Inputting them into the following formulas below, the % particulate matter can be calculated,

$$\frac{Amount\ of\ each\ component}{Total\ volume\ of\ soil} \times 100 = \%\ Component$$

Determination of Water Quality Parameters:

The physicochemical parameters were determined using the methods outlined by Arafat et al., 2021 and Udo et al., 2009

Dissolved Oxygen (DO): Dissolved oxygen was determined using HANNA dissolved oxygen (DO) meter Model HI 93246. This was done in situ by immersing the probe of the meter into the water and the reading on the LCD taken when it stabilized.

pH (Hydrogen ion concentration), Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS): These parameters were determined using HANNA multiparameter water tester model HI 98129. This was done by inserting the probe of the meter into the water sample and setting the mode to read the respective parameter using the keypad MODE.

Evaluation of Heavy Metals: The elemental analysis of (Mn, Pb, Fe, and Cr) was carried out according to the method of the Association of Official Analytical Chemists (AOAC, 2016). 2 mL of sample was digested using an acid mixture of nitric acid, perchloric acid, and sulphuric acid (HNO_3:$HClO_4$, H_2SO_4). 2 mL of the acid mixture was dispensed in the tube containing 2 mL of the water samples. The tubes were then placed in the digester under the fume cupboard and heated until a clear and colorless fume was noted. The contents of the tubes were allowed to cool and then diluted with 250 mL of distilled water. From the diluent, an aliquot of the samples was taken for the analysis of minerals using an Atomic Absorption Spectrophotometer (AAS).

Statistical Analysis: Data was statistically analyzed using Statistical Package for Social Sciences (SPSS) for Windows (Version 21). Analysis of Variance one way (ANOVA) was used to determine the level of significance of variations between the samples. Results were considered statistically significant when ($P<0.05$). Results obtained from soil and water analysis were expressed as mean values, with their standard deviation using the Duncan Multiple Range Test (DMRT).

Results and Discussion

Physiochemical Characteristics of Soil and Water Samples

Table 1 and Table 2 are the results for the physicochemical properties of soil and water samples collected from the Kanshio and North Bank mechanic sites in Makurdi, along with their respective control samples. In the soil samples, North Bank exhibited a slightly more alkaline pH of 7.25 compared to Kanshio's 6.98. Both values fall within NESREA's acceptable range of 6.5–8.5, indicating no significant pH imbalance. Additionally, North Bank demonstrated a higher moisture content of 14.23% compared to Kanshio's 11.28%, suggesting that the soils at North Bank are better at retaining water. The Cation Exchange Capacity (CEC) was significantly higher in Kanshio at 4.19 meq/100g, while North Bank recorded 3.55 meq/100g, indicating that Kanshio's soil may be more effective at holding nutrients. Both locations had a high sand content of approximately 80%, although the control soils contained slightly more clay. In the water samples, all pH values were within NESREA's recommended range of 7.0–8.5. However, Kanshio water had the lowest pH at 6.80, while the Kanshio Control had the highest at 7.40, suggesting minor pH fluctuations due to mechanical activities. Electrical Conductivity (EC) levels were significantly below NESREA's limit of 400 µS/cm, indicating low salinity in all water samples. Total Dissolved Solids (TDS) remained under the permissible limit of 500 mg/L, although Kanshio water recorded a slightly higher TDS of 88.75 mg/L compared to the controls, which may indicate potential contamination. Dissolved Oxygen (DO)

Table 1: Physicochemical Composition of Soil Samples Across Locations in Makurdi

SAMPLES	pH	Percentage Moisture (%)	CEC (meq/100g)	Particulate Nature		
				Clay (%)	Sand (%)	Silt (%)
Kanshio	6.98 ± 0.15^b	11.28 ± 0.22^c	4.19 ± 0.18^a	12.41 ± 0.21^{ab}	80.64 ± 0.27^b	7.20 ± 0.25^a
North Bank	7.25 ± 0.06^a	14.23 ± 0.22^b	3.55 ± 0.29^b	12.89 ± 0.44^a	80.81 ± 0.53^b	6.31 ± 0.17^b
Kanshio Control	7.13 ± 0.05^a	21.05 ± 0.39^a	2.48 ± 0.27^c	11.83 ± 0.52^b	81.66 ± 0.49^a	6.52 ± 0.23^b
North Bank Control	6.90 ± 0.08^b	21.06 ± 1.59^a	2.31 ± 0.16^c	10.54 ± 0.48^c	82.27 ± 0.28^a	7.09 ± 0.23^a
P-Value	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
NESREA	6.5 – 8.5	-	-	-	-	-

Note: Means on the same column with different superscripts differ significantly

pH = potential of hydrogen; CEC = Cation Exchange Capacity; NESREA = National Environmental Standards and Regulations Enforcement Agency

Table 2: Physicochemical Composition of Water Samples Across Locations in Makurdi

SAMPLES	pH	E.C (µS/cm)	TDS (mg/L)	DO (mg/L)	Turbidity (NTU)
Kanshio	6.80 ± 0.14^d	55.26 ± 0.91^a	88.75 ± 6.29^{bc}	4.05 ± 0.37^a	0.48 ± 0.05^a
North Bank	7.20 ± 0.08^b	61.05 ± 1.44a	85.50 ± 9.40^{bc}	4.25 ± 0.52^a	0.50 ± 0.05^a
Kanshio Control	7.40 ± 0.08^a	42.08 ± 0.18^b	98.25 ± 10.99^{ab}	4.38 ± 0.46^a	0.39 ± 0.06^b
Northbank Control	6.95 ± 0.13^c	56.00 ± 7.48^a	84.25 ± 6.85^a	4.33 ± 0.19^a	0.35 ± 0.20^b
P-Value	<0.001	0.145	0.002	0.692	0.002
NESREA	7.0-8.5	400	500	4.0-5.0	5.0

Note: Means on the same column with different superscripts differ significantly

E.C = Electrical Conductivity; TDS = Total Dissolved Solid; DO = Dissolved Oxygen;

levels were consistent across samples, averaging around 4.0 mg/L, which is within NESREA's range of 4.0–5.0 mg/L, suggesting adequate oxygen levels for aquatic life. Turbidity was marginally higher in the water from Kanshio and North Bank, ranging from 0.48 to 0.50 NTU, compared to the controls, yet still well below the NESREA limit of 5.0 NTU, indicating minimal particulate pollution.

Heavy metal distribution in soil and water

The results for heavy metal concentrations in soil and water samples from the Kanshio and North Bank mechanic sites are presented in Table 3 and Table 4. In the soil samples, North Bank exhibited a significantly higher concentration of Mn at 1.24 mg/kg, while Kanshio recorded only 0.28 mg/kg. Conversely, Fe levels were much higher in Kanshio at 19.48 mg/kg compared to North Bank's 11.41 mg/kg. Both sites showed elevated levels of Pb and Cr, with Kanshio having greater concentrations of Pb (3.14 mg/kg) and Cr (1.04 mg/kg) than North Bank, which had 2.78 mg/kg and 0.57 mg/kg, respectively. Control samples indicated much lower concentrations of all metals, suggesting possible contamination from mechanic activities at both locations. Nevertheless, the heavy metal concentrations in all samples were well below NESREA's regulatory limits, especially for Pb (164 mg/kg) and Cr (100 mg/kg). In the water samples, no Mn or Pb was detected in any of the water from both sites or the control. Fe concentrations were low, with Kanshio and the control showing similar values around 0.02 mg/L, slightly higher than North Bank's 0.01 mg/L. Cr levels were not detectable in the water samples from any location. All measured values in water remained within NESREA's guidelines, indicating minimal heavy metal contamination in the water sources near the mechanic sites.

The pH levels of soils from the North Bank and Kanshio mechanic sites were slightly alkaline, measuring 7.2 and 6.9, respectively, which falls within NESREA's acceptable range of 6.5 to 8.5. This finding is consistent with the work of Okoronkwo et al. (2006), who noted a similar slightly alkaline pH in mechanic site soils in Owerri, likely due to the presence of metallic contaminants like Pb and Fe. In contrast, Nwachukwu et al. (2010) reported more acidic soils in mechanic villages in Lagos, which may be attributed to greater degradation or fuel leakage.

The moisture content was higher at North Bank (14.23%) compared to Kanshio (11.28%), indicating better water retention. This observation aligns with

Table 3: Mean Heavy Metal Concentration of Soil Samples Across Locations in Makurdi

SAMPLES	Mn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)	Cr(mg/kg)
Kanshio Soil	0.28 ± 0.04^{b}	19.48 ± 3.33^{a}	3.14 ± 0.15^{a}	1.04 ± 0.14^{a}
North Bank Soil	1.24 ± 0.10^{a}	11.41 ± 1.79^{b}	2.78 ± 0.28^{b}	0.57 ± 0.06^{b}
Kanshio Control	0.22 ± 0.01^{bc}	4.73 ± 0.73^{c}	0.12 ± 0.02^{c}	0.30 ± 0.02^{c}
North Bank control	0.14 ± 0.04^{c}	3.91 ± 0.49^{c}	0.12 ± 0.01^{c}	0.15 ± 0.07^{d}
P-Value	<0.001	<0.001	<0.001	<0.001
NESREA	–	–	164	100

Note: Means on the same column with different superscripts differ significantly

Mn = Manganese; Fe = Iron; Pb = Lead; Cr = Chromium

Table 4: Mean Heavy Metal Concentration for Water Samples Across Locations in Makurdi

SAMPLES	Mn (mg/l)	Fe (mg/l)	Pb (mg/l)	Cr (mg/l)
Kanshio	0.00 ± 0.00	0.02 ± 0.01^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
North Bank	0.00 ± 0.00	0.01 ± 0.00^{b}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
Kanshio Control	0.00 ± 0.00	0.02 ± 0.00^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}
Northbank Control	0.00 ± 0.00	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}
P-Value	0.000	<0.001	0.024	0.756
NESREA	0.05	0.1	–	–

Note: Means on the same column with different superscripts differ significantly

Mn = Manganese; Fe = Iron; Pb = Lead; Cr = Chromium

Olayinka and Alo (2004), who found that mechanic site soils with increased clay and silt content tend to retain more moisture.

Additionally, Kanshio exhibited a higher Cation Exchange Capacity (CEC) of 4.19 meq/100g, compared to North Bank's 3.55 meq/100g, which is consistent with the findings of Odjegba and Atewolara-Odule (2016), who associated higher CEC values with soils rich in organic matter and clay. In the water samples, pH levels were within NESREA's acceptable range of 7.0 to 8.5, corroborating the results of Akan et al. (2012), who reported similar findings in water samples near mechanic sites in Kaduna. The electrical conductivity (EC) levels were below NESREA's threshold of 400 µS/cm, supporting the findings of Olaniran et al. (2013), who also noted low EC in water near mechanic sites in Port Harcourt. Although turbidity levels were elevated (0.48–0.50 NTU) compared to control samples, they remained below NESREA's limit of 5.0 NTU, similar to the results reported by Adie et al. (2009) in water near mechanic sites in Ibadan. However, the higher total dissolved solids (TDS) at Kanshio (88.75 mg/L) indicate potential contamination from site activities, as noted by Osibanjo and Ajayi (2017).

The levels of heavy metals in the soil, such as Pb and Cr, were found to be higher at Kanshio than at North Bank. This finding is consistent with Adekola et al. (2012), who reported increased levels near mechanic sites in Ilorin. Nevertheless, the concentrations of these heavy metals remained below the limits set by NESREA (164 mg/kg for Pb and 100 mg/kg for Cr), which aligns with the observations made by Eze and Agbo (2011). In contrast, the Manganese (Mn) levels were higher at North Bank, supporting the findings of Ibeto et al. (2013), who attributed similar results to residues from tires and brake pads. Water samples showed no detectable levels of Pb, Mn, or Cr, which is in agreement with Oyeku and Eludoyin (2010), who reported low heavy metal contamination in water sources in Ibadan. The Fe concentrations in the water samples (0.01–0.02 mg/L) were also within safe limits, consistent with the findings of Ikhane et al. (2015), who noted similarly low levels in water near mechanic sites.

Conclusion

This study has provided important insights into the contamination levels of soils and water surrounding mechanic sites in North Bank and Kanshio, particularly in relation to NESREA standards. The soils exhibit slight alkalinity that remains within acceptable limits; however, the detection of heavy metals like Pb and manganese, especially at the Kanshio site, points to significant contamination associated with mechanic activities. While the concentrations are below NESREA's permissible limits, their presence indicates ongoing pollution that could potentially worsen over time. The water samples generally fell within safe limits for most parameters, but the higher levels of total dissolved solids (TDS) at Kanshio suggest that runoff from site activities is impacting water quality. From a broader perspective, this study supports trends observed in previous research throughout Nigeria, where mechanic sites are known to contribute to localized environmental pollution. However, the relatively lower contamination levels compared to studies from larger cities like Lagos indicate that while the risk exists, there is a chance to implement preventive measures now, before the situation escalates.

This study therefore suggests that regular monitoring of soil and water in and around mechanic sites should be conducted by relevant environmental agencies to ensure compliance with NESREA standards. This will help in the early detection of pollution and enable timely interventions to prevent further ecological degradation. Mechanic sites should adopt environmentally friendly practices in waste disposal, such as proper handling and disposal of used oils, batteries, and other hazardous materials. This will reduce the leaching of harmful substances into the soil and water bodies, thereby minimizing contamination. Environmental awareness and training programs should be organized for operators of mechanic sites. These programs should focus on the importance of environmental protection, proper waste management practices, and the long-term benefits of maintaining clean surroundings. And also, bioremediation techniques, such as the use of microorganisms to degrade harmful pollutants, be introduced in contaminated areas. This could help in restoring the soil and water quality over time.

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Status of Wetland Governance in Lake Cluster of Pokhara Valley: A case study of the Phewa, Begnas, and Rupa Lakes

Krishna Prasad Sigdel[1], Narayan Prasad Ghimire [1, *], Madhav Bahadur Karki[2], Binod Dawadi[3], Pabin Shrestha[4]
[1]Central Department of Botany, Tribhuvan University, Kathmandu 44613, Nepal
[2]Institute of Forestry, Tribhuvan University
[3]Central Department of Hydrology and Meteorology, Tribhuvan University, Kathmandu 44613, Nepal,
[4]Conservation Development Foundations (CODEFUND), Koteshwor-32, Kathmandu, Nepal
*Correspondence: np.ghimire@cdbtu.edu.np

Abstract

This study examines the status of the governance of Phewa, Begnas, and Rupa Lakes of Pokhara valley in Gandaki province, Nepal. These lakes constitute the Ramsar designated lake cluster site. The assessment of wetland governance was done through a comprehensive literature review, focus group discussion and key informant interview of representatives from 13 governmental and non-governmental organizations. Using the Integrated Lake Basin Management framework of the International Lake Environment Committee, the study evaluates governance based on six pillars: Institution, Policy, Participation, Information, Technology, and Finance. A governance assessment matrix with 10 indicators was used to score these pillars on a scale from 1 (lowest) to 7 (best). The study findings indicate that governance in these lakes is generally weak (low), except for the Institution and Policy pillars, which scored higher but fell in average scale. Among the three lakes, Rupa Lake had the highest governance score, while Technology, Information, and Finance were the weakest pillars across all lakes. There is no designated strong agency responsible for Ramsar site management in provincial level, although the Ministry of Forest and Environment, Gandaki Province has authorized the Lake Conservation and Development Authority to address wetland issues. Community-led Lake Resources Cooperatives have contributed to environmental improvements and provisional services. However, wetland area and biodiversity loss remain a concern. Additionally, weak coordination among provincial and local government agencies hinders effective governance. Strengthening institutional coherence, better enforcement of rules and regulations and consolidating efforts across agencies and stakeholders are necessary to improve governance and ensure sustainable wetland management in the future.

Key words*:* *biodiversity, community, Integrated Lake basin management, Lake institution, Wetland management*

Introduction

Governance basically refers to the structures and processes through which a society makes collective decisions and shares power within the formal and informal institutions of the community. They are the horizontal and vertical linkages among organizations and social groups engaged in decision-making, negotiation, and managing trade-offs (Young, 1992; Moench et al., 2003; Cookey et al., 2016). Governance of lake or wetland resources is a socio-political and technical processes through which authority and power are applied in running lakes and advocating for the common interests of people concerning development and conservation. In governance, it brings about a shift from a more centralized authority to a decentralized one wherein roles and responsibilities extend beyond the government hierarchy. It depicts not only state actions but all other actors such as communities and NGOs encouraging effect on resource management (Lemos & Agrawal, 2008; Juarez-Aguilar, 2010). The authority here usually relates to institutional legitimacy and capacity, where local governments and their agencies become the core actors (Brillo, 2023). Lake governance has contemporary dimensions and consists of the interplay of policies, laws, norms, institutions, and processes in the making, implementation, and accountability of decisions impacting lakes and their users (Pokharel, 2020). The International Lake Environment Committee (ILEC, 2005) developed the Integrated Lake Basin Management (ILBM) approach. It provides a governance framework aimed at enhancing lake basin environments and conserving biodiversity for sustainable development. Nepal has been involved in ILBM activities from the first exposure of National Lake Conservation Development Committee (NLCDC), the lake management authority of the Government of Nepal at the 12th World Lake Conference held in Jaipur/Rajasthan, India in 2007 (Pokharel,2009).

The ILBM is a management framework that promotes lake management approaches based on the proper understanding of the biophysical characteristics of lake ecosystems and interactions between lake ecosystems and humanity (Muhandiki et al., 2014). ILBM emphasizes on six pillars of governance such as Institutions, Policies, Participations, Information, Technologies and Finance (ILEC, 2005; ILEC, 2007; Pokharel, 2020). These six pillars are necessary components for any management response to be effective. The government of Nepal has been adopting this prescription to improve lake basin governance since 2006, and ever after federal restructuring through National Lake Conservation Development Committee (MoFE, 2018).

ILBM applications became visible in Nepal only after the country accepted the ILBM approach and documented it in National Ramsar Strategy and Action Plan (2018-2024). In Kaski district, the Gandaki Province and local governments are engaged in managing Lake Cluster of Pokhara Valley, the Ramsar site, and other wetlands by consolidating the basin-level governance following ILBM

The LCPV and ILBM approaches are aligned with the core principles that establish management and governance framework of wetland sites designated as Ramsar sites. The Ramsar Convention is an inter-governmental treaty adopted in 1971, and its initial focus is on the conservation of waterfowl habitats (www.ramsar.org). Over the years, recognizing wetland ecosystems for biodiversity conservation and improving human health and wealth, the convention broadened its scope into conservation and wise use of wetlands, listing wetlands of international importance (the Ramsar list) and broadening international cooperation. Also recognizing wetlands integral element of environment and sustainable development (Poudel, 2009), the Convention came into enforcement in Nepal in 17 April 1988. Nepal has 10 Ramsar sites including lake cluster of Pokhara valley (https://www.researchgate.net). Such multilateral international environmental agreements also guide national policies and laws in other wetland related areas. Numerous sectoral agencies claimed authority over its governance but failed to deliver effective results (Joshi & Bhandari, 2016). This study focuses on the following key governance principles of the Ramsar Convention: a. Integrated management; Stakeholder involvement; c. Policy and legal frameworks, d. Incentives for conservation and e. addressing conflicts.

Materials and Methods

Study Area

Pokhara Valley lies in the lesser Himalaya of Nepal with an average elevation of 822 m and is the capital city of Gandaki province.The nine-lake cluster in Pokhara Valley, including Phewa, Begnas and Rupa was listed as Ramsar sites of Nepal in 2016 which has a total area of 261 km^2 including their riparian areas (Ghimire and Regmi, 2024). The LCPV lies on a top of a gigantic debris fan from a cataclysmic flashflood that, according to geologists, was caused by the Seti River bursting through a landslide or avalanche dam in its headwaters below Annapurna IV about 800 years ago (RIS 2016). The lake areas consist of layered clastic deposits with gravel, silt, and clay from the Quaternary age, brought from the Annapurna range by series of catastrophic debris flow (Yamanaka et al., 1982). Morphologically, LCPV is made of five major land units, including alluvial plains and fans, alluvial plains, ancient river terraces (tars), and moderate to steep mountain slopes. Agriculture is concentrated in alluvial plains and river terraces (GoN 2014).

This study focuses on Phewa, Begnas and Rupa Lakes, which are the major lakes under the LCPV, Nepal (Fig. 1). Phewa is the largest lake in cluster and second largest lake in Nepal by area with a surface area of ~4 km2 in 2018 (Watson et al., 2018). The Phewa Lake is the main attraction for tourism in Pokhara. Begnas is the second biggest lake in LCPV at an elevation of 650 masl covering an area of ~2.98 km2in 2019 (Thakuri et al., 2021).). The lake lies at the foothills of Himalayan Mountain at an elevation of 782 masl, symbolizing a lake with the intense anthropogenic burden from various pollutants and contaminants. It bears an external area of 4.35 Km2 and extreme depth of 22.5 m (Sharma et al., 2015). Likewise, Rupa is the third largest lake at an elevation of 600 masl with an area of 1.35 km2(MoFE, 2018

The climate of Pokhara is controlled by Indian monsoon in summer seasons and westerly wind systems in winter seasons (Khadka et al., 2023). The LCPV region receives maximum total annual rainfall of around 3500 to 4,000 mm compared to eastern (~1600 mm) and western (~1500 mm) parts of Nepal and has a humid subtropical climate (Sharma et al., 2020; Sigdel et al., 2022). The lake regions have been experiencing changes in temperature (0.3°C increase per decade) and rainfall (insignificant increase). Similarly, there is a notable 11.39% decline in the surface area of Phewa Lake since 1989, while the surface areas of Begnas and Rupa have remained relatively stable. Changes in LULC show an increase in forest cover (+47 to 64%) and decrease in croplands (-36 to 59%) across all watersheds (Sigdel et al., 2025).

The vegetation in the area is a mosaic of sub-tropical and temperate broad-leaved forests, including Sal (Shorea robusta) in the south, riparian forests along the banks of the Seti River and its tributaries,

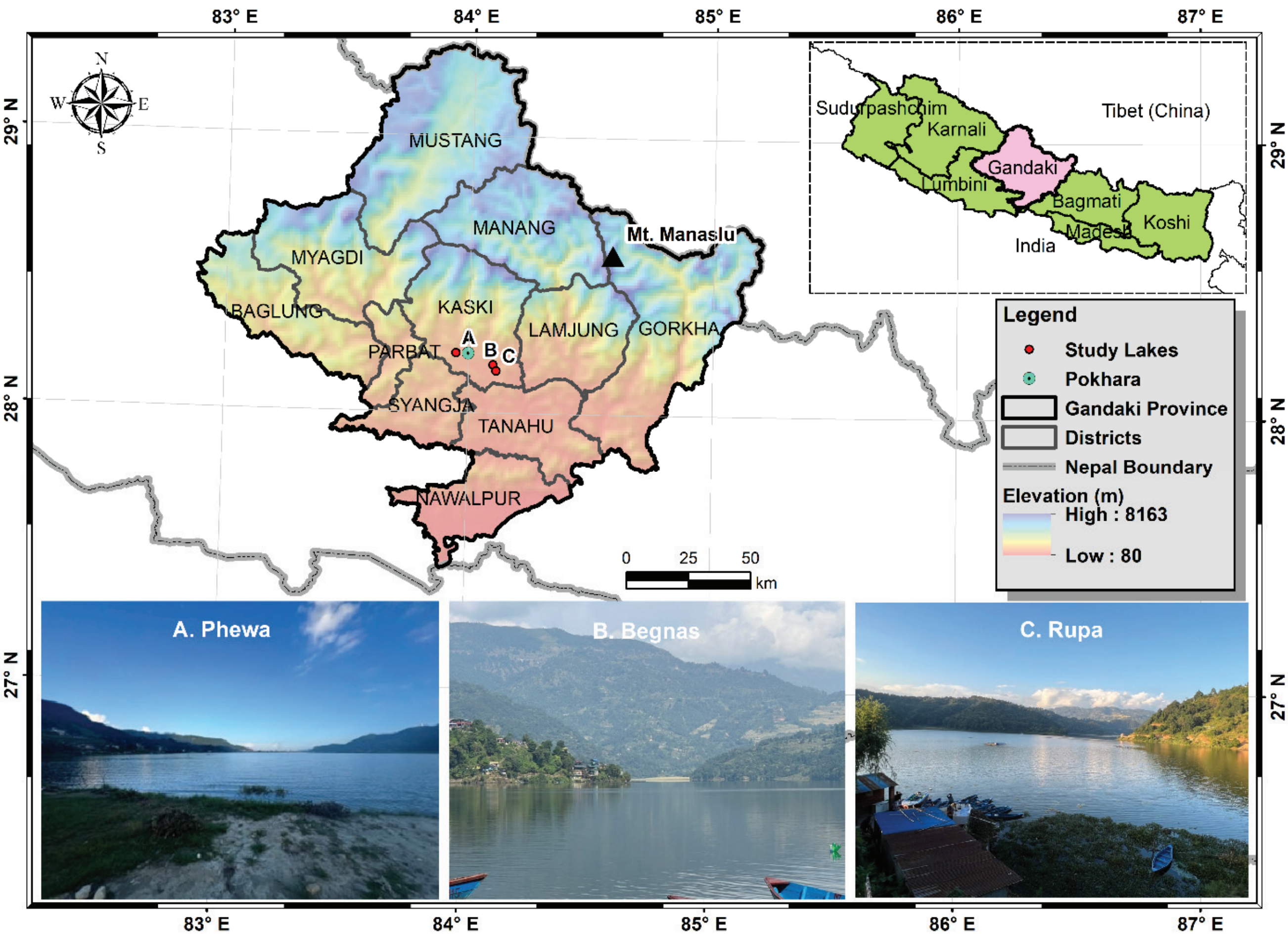


Figure 1: Overview of the study area and three lakes. The inset displays Gandaki Province in Nepal, while the zoomed-in panel offers a detailed view of the specific locations of the three lakes in Gandaki province. The lakes pictures in lower panel are captured by first author, which are the primary focus of this research.

and Schima-Castanopsis forests in the north and west (MoFE, 2018).In the Phewa lake basin, the subtropical forests dominant on the southern and western sides. A significant portion of the Panchase Forest Protected Area, located within the Harpan sub-watershed of Phewa, includes the historic Hill-top (Lek) called 'Panchase', which is rich in endemic orchids. The basin of Begnas and Rupa lakes are mainly covered by sub-tropical vegetation, including hill Sal forests and Chilaune-Katus forests (MoFE, 2018).

Methodology

This involved meticulously examining a wide range of sources, including scientific articles, institutional and government reports, and relevant news articles that focus on lake management and governance. By synthesizing information from these diverse materials, we aimed to ensure a thorough and accurate understanding of the current state of lake basin management practices. Qualitative tools for the study included desk research, observation key informant interviews (KII). Open-ended and pretested questionnaires for key-informant interviews, focused group discussion (FGD), observations were used for data collection. The study sites (Phewa, Begnas and Rupa Lakes) were visited for two times in 2024 representing two different seasons during monsoon (June-August) and autumn (September-November) seasons.

Key Informants' Interview (KII)

For evaluating lake basin governance, 13 wetland related institutions personal were selected as Key Informant Interview (KII) as institutions involved in managing targeted lakes of LCPV. Assessment matrix was designed to assess the status of governance to evaluate the strength of Institution, Policy, Participation, Information, Technology and Finance pillars of ILBM following the Governance Diagnosis System (GDS)(Juarez-Aguilar, 2010) after its modification by Pokharel(2020).

Focus Group Discussion

Focus group discussion was aimed to draw out information on environmental degradation and conservation efforts for the wetland management and wetland governance. A total of three Focus Group Discussions (FGDs) were organized with lake conservation and management committees of Phewa, Rupa, Begnas lakes. During focus group discussion, Community Forest User Groups, Lake Conservation Committee, Boater's Association, Fishing Cooperatives, Mother Groups, Local Youth Club and others, elder persons living at the nearby locations of the lake clusters Water User Group, Informal Irrigation User Group, Fishermen Group, Lake Dependent Communities (Jalahari) were involved. Checklists were used as a tool for FGD.

For analysis, assessment matrix was devised in MS Excel 2016, which uses 10 indicators for each of the six governance pillars. The amplitude of governance improvement has been ranked using a scale from '1' to '7', where '1' is ranked as the weakest value (lowest) and'7' as the strongest (best) governance value. All the indicators are expressed in diagnostic question to be responded by concerned agencies reciprocating their engagement in targeted lakes. Each question needs to be answered with a score (from 1 to 7) that fits best in the case of individual wetlands. The average scores for each governance pillar were calculated and plotted for analysis. An overall summary of each governance pillar's perceived importance was also completed by analyzing mean scores. A radar diagram for lake depicting each pillar was developed to determine the strength of ILBM pillars.

Results and Discussions

Status of governance pillars in Phewa, Begnas and Rupa lakes

Institution

There are multiple interrelated layers of institutions that overlap in their jurisdiction in managing the resources of these lakes. The Ministry of Forest and Environment (MoFE) at the federal level is the governmental institution playing the role of the lead agency for administrating Ramsar implementation, through its departments such as Department of National Parks and Wildlife Conservation (DNPWC) and Department of Forests and Soil Conservation (DoFSC) (Pokharel, 2009; 2022). Basin Management Center (BMC) based in Gandaki province, is a federal-level institution that works under the DoFSC, focuses on watershed management. At Province, the Ministry of Forests and Environment (MoFE), leads lake management activities. Lake Conservation and Development Authority (LCDA) and Division Forest Office, Kaski, work under the Ministry of Environment, Gandaki provincial government Pokhara Metropolitan City (PMC), Rupa Rural Municipality and Annapurna Rural Municipality have also dedicated roles as institutions for managing lakes. All these entities from federal to province and local levels, they do coordinate, allocate budget and implement ILBM plan of LCPV. Each local-level government has environment sector for lake conservation. Conservation partners, Non-Government Organization (NGO), academia, research institutions and private sector act in parallel as advocates and supporters in managing the lake basin watersheds (Figure 2).

In stakeholder respondent analysis, the institutional pillars of all three lakes were ranked good, since they all scored more than the 3.5 in an average in the governance radar diagram (Figs. 3, 4, 5 and 6). This means that institutions exist in this lake basin area and are functioning well. Institutions are at the pillars of lake basin management since they implement the measures for management. For example, they administer laws, provide a forum for involving stakeholders, gather and store knowledge, sometimes establish policies, etc. (ILEC, 2005). In addition, other institutions are also associated with lake management. In these lakes, mainly three levels of institutions are functioning. At Federal level, the MoFE through the Department of National Parks and Wildlife Conservation (DNPWC), Department of Forests and Soil Conservation (DoFSC), Forest Research and Training Center (FRTC) and Department of Plant Resources (DPR) implements policies, programmes and projects. Basin Management Center (BMC),

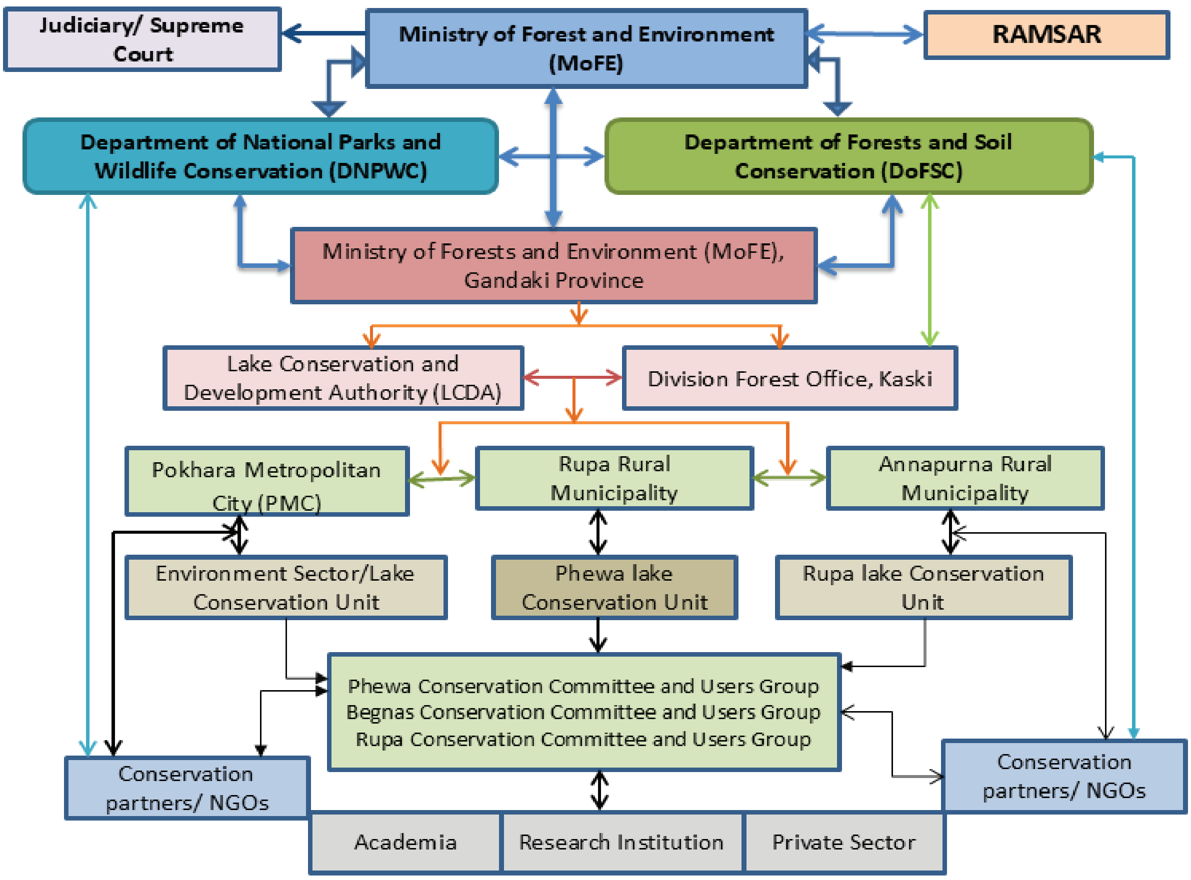


Figure 2: Institutional arrangement of Phewa, Begnas and Rupa Lakes

Gandaki is a federal-level institution that works under the DoFSC. Wetlands management involves collaboration with various ministries, including the Ministry of Agriculture and Livestock Development (MoALD), Ministry of Land Management and Cooperatives (MoLMC); Ministry of Education, Science and Technology (MoEST); Ministry of Energy, Water Resources and Irrigation (MoEWRI); Ministry of Industry, Commerce and Supplies (MoICS); Ministry of Federal Affairs and General Administration (MoFAGA.); Ministry of Culture, Tourism and Civil Aviation (MoCTCA); National Planning Commission (NPC); and Water and Energy Commission Secretariat (WECS). The National Wetland Coordination Committee (NWCC) under MoFE coordinates efforts across these ministries. In Phewa Lake, the Nepal Electricity Authority (NEA) utilizes the Lake water to generate electricity. The Nepal Tourism Board promotes the Lake as a major tourist attraction and recreation area. The Federal Ministry of Finance is also a stakeholder since it collects tax generated through revenue from various goods and services catered to the tourists in the Lakeside area.

At provincial level, all three lakes lie in Gandaki Province. The Ministry of Environment (MoFE), Gandaki province has established Lake Conservation and Development Authorities (LCDA) to promote the sustainable conservation and wise use of all lakes in the provincial level of Gandaki Province (LCDA, 2024). The other relevant sectorial agencies for implementation include the Forest Directorate, Division Forest Office, Forest Research and Training Center, Soil and Watershed Management Office, Water Resource and Irrigation Development Division Office, Underground Water Resource and Irrigation Office Pokhara, Infrastructure Development Office, Urban Development and Building Office, Transportation Management Office, Panchase Protected Forest Office, and Vocational and Skill Development Training Centre. Additional federal agencies operating in Pokhara include the Basin Management Center, Rupa Taal Conservation Integrated Irrigation Project, Pokhara Tourism Board, and Fishery Research Station, Begnas.

Key urban management initiatives include the Pokhara Valley Lake Restoration Program and various sustainability policies led by the Gandaki Province Government and Pokhara Metropolitan Office. These efforts aim to improve infrastructure, manage solid waste, and balance urban growth with environmental conservation (Department of Urban Development and Building Construction [DUDBC], 2022; Pokhara Valley Lake Restoration Program, 2021). Likewise, Annapurna Rural Municipality and Rupa Municipality play significant roles in Conserving Phewa and Rupa lakes.

At community level, LI-BIRD is a leading NGO engaged in agriculture biodiversity research and development at the local level. The Pragya Cooperative Implements Non-timber forest products (NTFP) related activities and has a nursery in the Begnas Lake basin. The Machhapuchre Development Organization (MDO) is engaged in biodiversity-based livelihoods, including orchid conservation in the Panchase area. The Boat Associations in Phewa and Begnas lakes provide recreational boating services in their respective lakes. Rupa Lake Restoration and Fishery Cooperative is a key local institution that supports the sustainable functioning of Rupa Lake. In addition, numerous conservation partners are active in the lake area. Key international partners include International Union for Conservation of Nature (IUCN) Nepal, World Wide Fund for Nature (WWF) Nepal, and International Centre for Integrated Mountain Development (ICIMOD), Zoological Society of London (ZSL), International Water Management Institute (IWRMI) Nepal, and Conservation and Development Fund (CODEFUND)Notable NGOs working in the region are the Society for Wildlife Research and Conservation, Bats Friend Pokhara, Bird Conservation Nepal (BCN), Forest for Transformation Nepal, Union for Nature Conservation, and Forest Alliance Nepal.

Policy and Legal Framework:

The Constitution of Nepal has divided the sovereign powers and nation capabilities amongst three ranges of governments i.e. federal, nation and nearby level (Article 56) envisioning a cooperative, coexistent and coordinative device of federal governance (Article 232). For clarity, the Constitution has divided jurisdictions of the nation capabilities categorically where 'wetland conservation' is below federal jurisdiction. But wetland capabilities and offerings like electricity, irrigation, consuming water, navigation, and tourism are frequently unfold over all of the ranges (Schedules five to nine). In addition to that, it has said that the rights now no longer certain withinside the schedules fall below the prerogative rights of the federation (Article 58).

Our stakeholder respondent analysis also reflects the policy pillar of all three lakes, where scores are more than the average score of 3.5 in Governance radar diagram by respondents (Fig. 6). According to individual scores, Rupa lake (4.20) has higher scores as compared to Phewa (3.87) and Begnas lake (3.54) (Figs. 3, 4 and 5). There are policies, and they all function to govern the lakes. Policies act as principles to guide decisions in the sector and are implemented as procedures (ILEC, 2005). As Phewa, Begnas and Rupa Lake are included in the Ramsar sites, they are subjected to follow the Ramsar guidelines. The Convention on Biological Diversity (CBD) and International Trade in Endangered Species (CITES) function alongside Ramsar Convention. These are Nepal's international commitments in the protection of environment. In addition, the Constitution of Nepal has divided the sovereign powers and state functions among three tiers of government, i.e., federal, provincial and local levels, envisioning a cooperative, coexistent and coordinative federal governance system.

Whatever the Constitution provides, the water sector is cross-cutting under the many prevailing strategies and policies. The Water Resources Strategy (2002) and National Water Plan (2005) have the concept of Integrated Water Resources Management (IWRM). At the setting of these strategies/policies, over two dozen of Acts prevail, and the most relevant to wetlands among these are Aquatic Protection Act (2017), National Parks and Wildlife Conservation Act (1973), Soil and Watershed Conservation Act (1982), Water Resources Act (1992) and Water Resources Policy (2020), Solid Waste Management Act (2011) and Irrigation Policy (2013). Besides many Acts, a few environmental standards and guidelines related to wetlands/ponds also prevail. Nepal's wetlands follow the guidelines of Nepal, especially the 4th Ramsar Strategic Plan (2016-2021), the Communication Education Participation and Awareness (CEPA) Strategy of Ramsar (2011-2015) and Nepal's National Wetlands Policy (2012). Local Government Operation Act (2017) also provides the rights for local government to directly engage in wetlands activities and Public-Private Partnership Policy (2072) and Public Private Partnership and Investment Act, (2019) also engage private sector in wetlands. Policy provision is not a gap, but many policies require mainstreaming, harmonization and implementation for their effectiveness (GoN, 2012; 2013; 2020).

Based on above legal footprint, and provisions set by way of means of the Constitution of Nepal 2015, the Gandaki province of Nepal has been very proactive to respond with coverage and legal framework for the basin level sustenance of lentic-lotic water system. The province has formulated the Forests and Watershed Policy of the Gandaki province-2018, that's the center coverage framework to cope with all of the problems of forests, vegetation and wildlife, biodiversity, watershed, wetlands, and grasslands of the country. This coverage strongly spelled out for the weather resilient and sustainable management of wetlands ecosystem (Bullet 2 under 'Ka'), incorporated control of lakes, wetlands, rivers and glaciers of the country (Bullet five under 'Ka')10, and for the environment management of the country ('Kha'). Next however very terrific one, the enactment of Lake Conservation and Development Authority Act-2018 which objectives to conserve, restore and manage lakes and their basins for the biodiversity and surroundings conservation for sustainable development and prosperity withinside the country.

Participation:

In respondent analysis, the participation pillar in wetland governance is high in the case of Rupa Lake that is 4.3, compared to Phewa Lake (2.8) and Begnas Lake (2.2) (Figs. 3, 4 & 5). Participation in Rupa Lake is satisfactory compared to the other two lakes. The three lake basins have a wide range of stakeholders due to the broad range of ecosystem services offered by these three lakes. Ecosystem-based adaptation (EbA) and Payment for ecosystem services (PES), these two mechanisms are to be adopted in three lakes, which may support to local people to remain engaged in lake activities. EbA Project in the Panchase area of Phewa piloted a PES mechanism that linked upstream and downstream communities, offering technical and financial support to reduce sedimentation in Phewa and improve livelihoods upstream (WWF Nepal, 2019). There is already a cooperative model in Begnas Lake and Rupa Lake consisting of the fishermen group and the Community Forestry User Group (CFUG) paying a certain amount of revenue to CFUG for conservation works in upstream of the lake. Rupa Lake Restoration and Fishery Cooperative directly involve the local people in fishery management and lake conservation. The PES mechanism in Phewa has been updated in 2024 and Pokhara Metropolitan and Annapurna Municipality acting the process of implementation of PES mechanism for the sustainable management of Phew Lake and its watershed areas. PES mechanism of Rupa Lake is already functioning. Participation in Rupa Lake appears strong because the EbA, PES and Cooperative model operate and function in the lake basin area.

Technology:

In our stakeholder respondent analysis, technology pillar score is low in ranking. Phewa (2.5), Begnas (2.3) and Rupa (2.9) were ranked weak in utilizing technology around the lake basin area (Figs. 3, 4 & 5). In this century and high-time, the role of technology is very important. Technology helps to conserve lake basin area in proper manner. These three wetlands at grass-root are being managed conventionally using indigenous technology and tools. In the past, Japan International Cooperation Agency (JICA) and Asian Development Bank (ADB) made efforts to improve the environment and sanitation of Pokhara City including the sewage management of Phewa Lake, but these mega projects terminated before completion and full implementation.

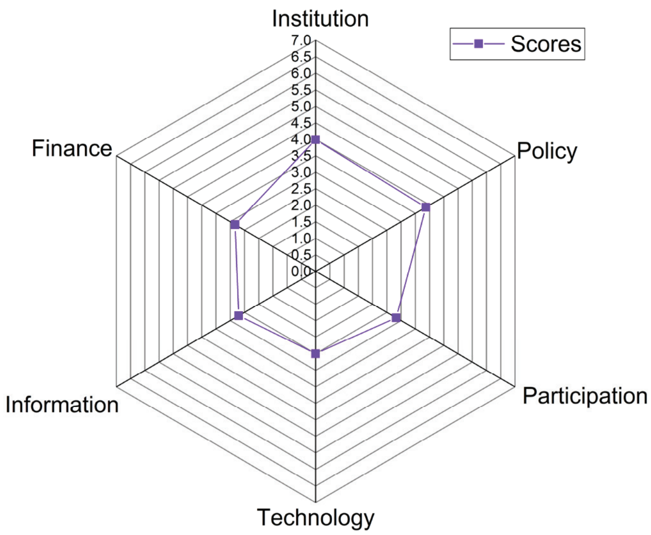
Information:

In stakeholder respondent analysis, scores in the information pillar in the radar diagram seem low in the Technology pillar. However, the information pillar of Rupa (3.3) scored more than the other Phewa (2.7) and Begnas lake (2.5) (Figs. 3, 4 & 5). Meaningful actions and decision-making are needed for reliable information (ILEC, 2005). Formulation of different strategies and policies are intended to produce various products and tools to generate conservation education and public awareness. Academic centers like Tribhuvan University, Institute of Forestry Pokhara and Kathmandu University have curriculum-based graduate programs for research-based information generation. Kathmandu University has also established a research laboratory in the Rupa Lake area to research Hydrology and Meteorology around the Rupa Lake basin area. The Resource Himalaya, an NGO, annually conducts a Graduate Symposium with a wetland's component. IUCN-Nepal, WWF-Nepal and ICIMOD along with universities are knowledge-generating institutions that publish and disseminate research-based knowledge. In addition, some non-governmental organizations like the Conservation Development Foundation (CODEFUND), Bird Conservation Nepal (BCN), Pokhara Bird Society (PBS), Local Initiatives for Biodiversity, Research and Development (Li-Bird), Green Governance, and so on also conduct field-based research and organize symposia in Phewa, Begnas and Rupa lake basin area.

Finance:

In our stakeholder respondent analysis, the finance pillar of three lakes scores lower than other pillars (Fig. 6). Rupa (3.4) scores higher in the governance pillar than in two other lakes. Stable finance is necessary to manage lake basins (ILEC, 2005). The government funding for the conservation and management of lakes comes from several key federal, provincial, and local sources. Ministry of Finance (MoF)allocates the national budget for the implementation of Ramsar provisions in Nepal, including the regular budget for Phewa, Begnas, and Rupa Lake. Under this budget, various ministries, including the Ministry of Forest and Environment (MoFE) and the Ministry of Culture, Tourism and Civil Aviation are provided with financial resources for initiatives related to natural resource management, including wetlands like the Phewa, Begnas and Rupa Lake.

Gandaki Provincial Government provides funding for lake management through Lake Conservation and Development Authority (LCDA) and other regional agencies. Local governments, particularly



Legend

Governance	Lowest	Lower	Low	Okay	Good	Better	Best
Score	1	2	3	4	5	6	7

Figure 3: Wetland Governance Diagnosis Radar Diagram of Phewa lake. Note: The legend is same for all radar diagrams in figures 4,5 and 6.

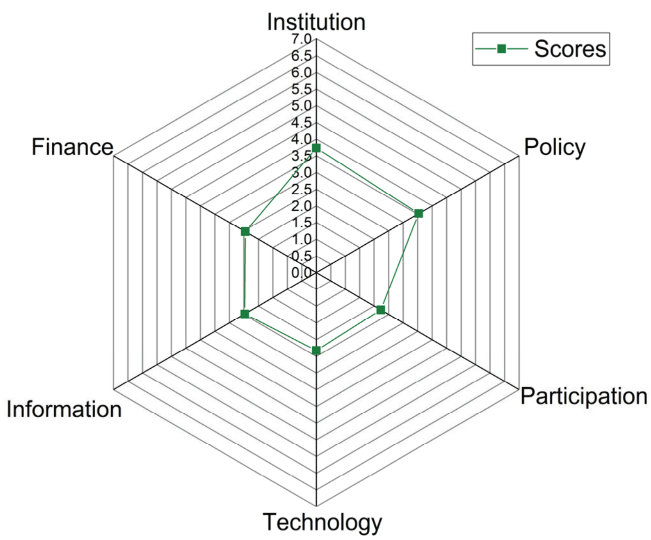


Figure 4: Wetland Governance Diagnosis Radar Diagram for Begnas lake.

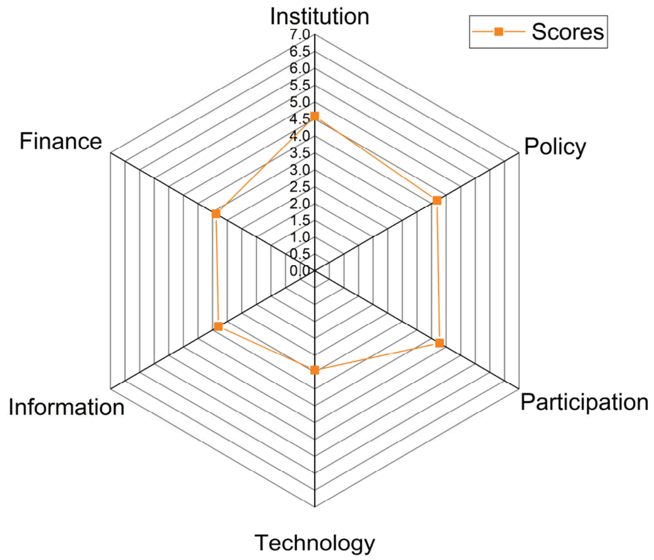


Figure 5: Wetland Governance Diagnosis Radar Diagram for Rupa Lake.

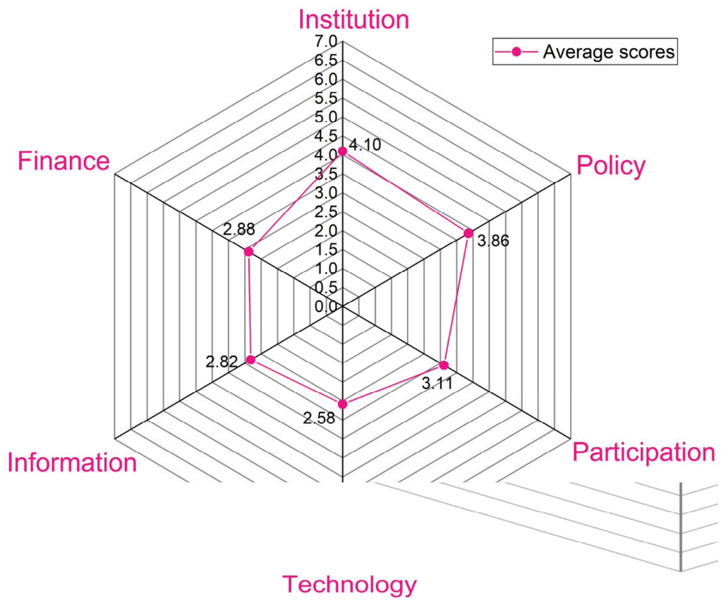


Figure 6: Overall Wetland Governance Diagnosis Radar Diagram obtained by average scores for Rupa, Begnas and Rupa Lakes governance.

Pokhara Metropolitan City and, Annapurna Rural Municipality and Rupa Municipality, play a crucial role in financing Phewa, Begnas and Rupa Lake conservation efforts. The Local Government Operation Act of 2017 empowers local governments to allocate budgets specifically for environmental management, encompassing the conservation of wetlands and lakes.

Conclusion

Community based as well as other non-government organizations are supporting governments and communities to strengthen six pillars of ILBM in Nepal in policies documentation, stakeholder engagement and communities' preparation. The Phewa, Begnas and Rupa lakes are three bigger lakes in the LCPV, where ILBM approach has been applied. Hence, this study aims to examine the extent of ILBM in these lakes. The significance of this study lies not only in its potential to enhance our knowledge of ILBM practices but also in its ability to inform and strengthen governance frameworks and management strategies for these vital water bodies. Effective governance is essential for balancing the diverse interests of stakeholders, including local communities, tourism operators, and environmental conservationists.

Based on the study findings, this study concludes that the six pillars - Institution, Policy, Participation, Technology, Information, and Finance- of Integrated Lake Basin Management (ILBM) for wetland governance are interconnected and interact with one another constantly. Overall, pillars in wetland governance in Phewa, Begnas and Rupa lakes have below-average scores except for institution (4.10) and policy pillars (3.86) with neutral score. None of the pillars were ranked good or above-good governance. Technology, Information, and Finance pillars are weak among others in this lake cluster. The study found an exemplary case of institutional arrangement in Phewa lake which scored higher compared those of Begnas and Rupa lakes. According to our results, Begnas and Rupa Lake's governance activities are not particularly focused on lakes but the overall watershed. The governance responsibility for Ramsar sites is not clearly assigned to either federal government (Ministry of Forests and Environment) or Division Forest Office (provincial government), or local governments such as Pokhara Metropolitan City and Rupa and Annapurna rural municipalities. There are policies and strategies related to lakes and wetlands, including dozens of acts backed by regulations and environmental standards. Conservation and management of lakes and wetlands in Nepal fall under different governmental organizations institutions with overlapping mandates. However, integrated wetland management actions are urgently needed to enhance Lake Basin governance.

There exists so many lakes and wetlands related policies and strategies including dozens of acts backed by regulations and environmental standards. Conservation and management of lakes and wetlands falls under several institutions, with overlapping mandates. The government of Nepal implemented National Ramsar Strategy and Action Plan (national policy framework to guide the implementation of Ramsar) in 2018. Next implementation plan is needed to prepare and such documents will be useful in the context of improving weak lake basin governance by the province, metropolitan and rural municipality. Payment for ecosystem services (PES) mechanism of Phewa lake has also been prepared and has to be implemented soon. Therefore, strengthening basin governance in LCPV is the next immediate priority to implement a drive of the Lake City of Nepal making Pokhara a combined key of tourism and biodiversity destination in Nepal. Phewa, Begnash and Rupa Lakes are major lakes of LCPV, other lakes are significant wetland resources of Nepal.

Conflicts of Interest

The authors declare no conflict of interest.

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E-Waste Management in Benue State: A Case Study of Mobile Phone Wastes in Makurdi Metropolis

Kajo Sarah, Eche Chris, Yager Gabriel
Department of Environmental Sustainability, Joseph Sarwuan Tarka University
*Correspondence: sokajo@cipessfuam.edu.ng

Abstract

Due to the rapid increase in population, rapid urbanization, increased technological advancement which has led to an increase in the use of Electrical and Electronic Equipment (EEE) worldwide, e-waste has become a critical environmental issue for many governments and the world. To address this challenge, this study investigates the management of mobile phone wastes in Makurdi, Benue State. Enquiries were made as to identify the sources, management and identification of those involved in phone waste management. Employing the descriptive research design using qualitative research and quantitative data in its approach through the use of semi-structured interviews conducted using questionnaires based on a sample size selected. The study explored the practices of e-waste disposal and recycling among residents to which a total of four hundred respondents were interviewed in ten (10) out of the eleven (11) council wards in Makurdi LGA. Findings revealed that 55.75% of mobile phones and accessories are sourced in the state, 29.75% from outside the state but within Nigeria and 14.5% came from outside Nigeria. A predominant reliance on informal recycling channels, with most mobile phones sold to scrap dealers (53.5%), primarily based outside the study area was also identified. The absence of formal recycling facilities within Makurdi exacerbates the issue, leading to indiscriminate dumping of phone waste. This research underscores the urgent need for a comprehensive e-waste management system in the region to mitigate environmental and health risks, recover valuable resources, and promote sustainable development.

Keywords: *Environmental, Recycling, Sustainable*

Introduction

Nigeria, like many developing nations, is experiencing rapid technological advancement, particularly in the telecommunications sector. The proliferation of mobile phones has connected millions of Nigerians, driving economic growth and social development. However, this digital revolution has also generated a significant and growing challenge: e-waste (Andeobu et al., 2023).Adama, et al. (2019) define e-waste as any electronic device that is either of the following; damaged beyond repair, whose life cycle has expired, has become obsolete, can still be used, but consequently rejected by the user. The commonality among the definitions of e-waste is that the device in question is no longer needed or useful to the initial owner.

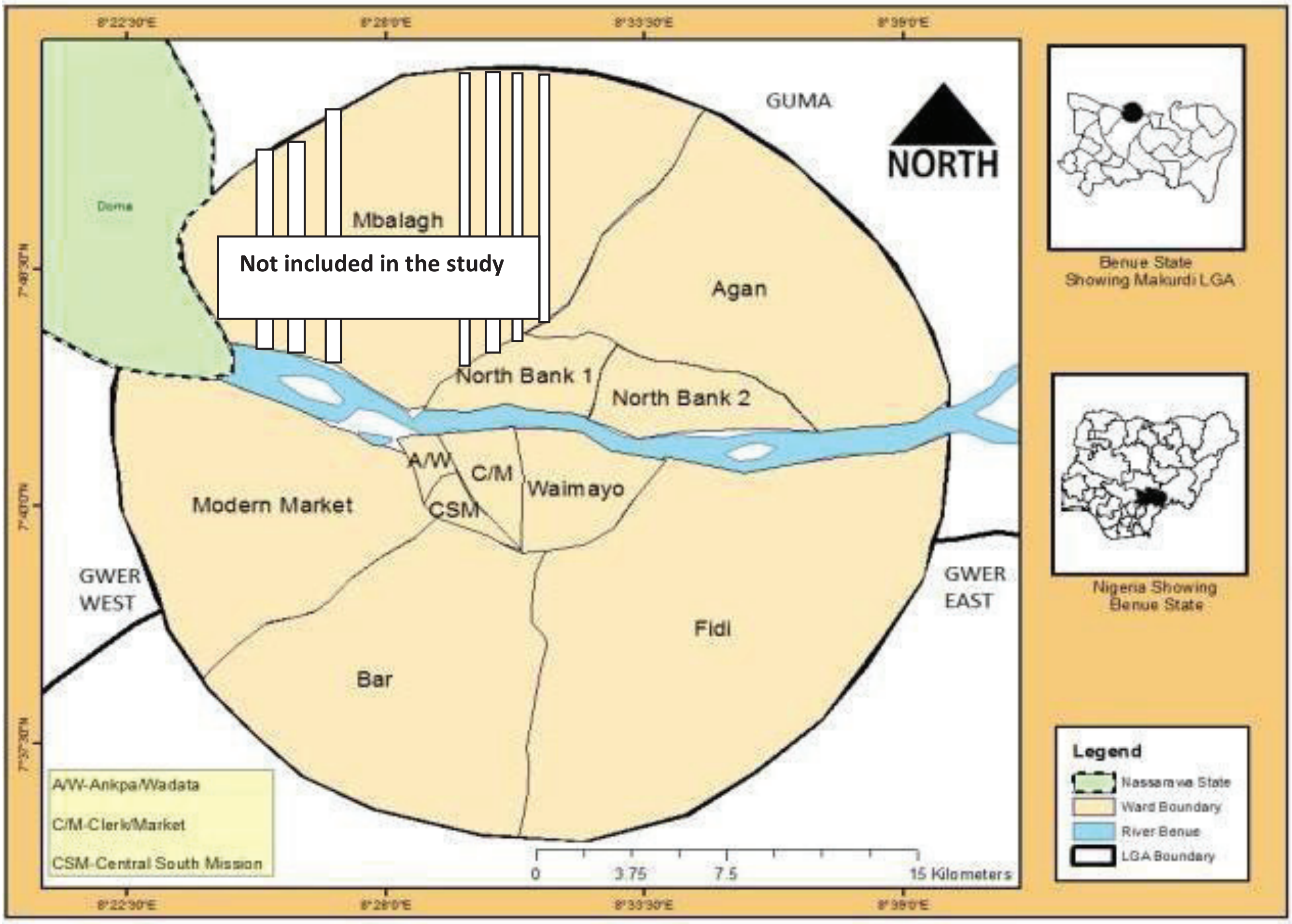
Technically, electronic waste is only a subset of Waste Electrical and Electronic Equipment (WEEE) as defined by OECD (Organization for Economic Co-operation and Development) as any appliance that uses an electric supply and has reached its end-of-life (Fon, 2018). According to Kuehr, et al. (2024), the world's generation of electronic waste is rising five times faster than documented e-waste recycling. According to Euro news, 3 Nov. 2022, Europe has the world's highest e-waste collection and recycling rate at 42.5% followed by Asia, at 11.7%, the Americas and Oceania at 9.4% and 8.8% respectively and Africa had the lowest rate at 0.9%. The monetary worth of e-waste raw materials is estimated to be $57.0 billion. However, only $10.0 billion worth of e-waste is recycled and recovered sustainably, offsetting 15.0 million tons (Mt) of CO_2 which is an important greenhouse gas that helps to trap heat in our atmosphere. Several studies have pointed out that failure to adopt appropriate recycling practices for e-waste may cause environmental disasters and health concerns to humans due to the presence of hazardous materials such as Lead, Mercury, Nickel, Polybrominated Diphenyl Ethers (PBDE's) and Polychlorinated Biphenyls (PCB's). Burning e-waste, a common practice in developing countries, may generate dioxins, furans, Polycyclic Aromatic Hydrocarbons (PAH's), Polyhalogenated Aromatic Hydrocarbons (PHAH's) and Hydrogen Chloride. Mobile phones by weight share only a small portion of total e-waste but due to factors like toxic nature of materials used, shorter life span and high energy requirements during production and use, its environmental impact has become a matter of concern. The Greenpeace report published in 2008 also indicated mobile phones as one of the major environmental threats in terms of e-waste generation, hence the need for this project in order to bring to the front burner amongst other environmental challenges, the dangers of this small but seemingly dangerous e-waste. Mobile phones, with their short lifespan and constant technological upgrades, have become a major contributor to the e-waste crisis in Nigeria. Improper disposal of these devices pose serious environmental and health risks due to the presence of hazardous materials such as lead, mercury, cadmium, and beryllium. These toxic substances can leach into the soil and water, contaminating ecosystems and posing threats to human health (Okwu et al., 2022). Furthermore, developing countries, including Nigeria, by virtue of being third world economies are disposed to being major consumers of used Electrical Electronic Equipment (Okorhi et al., 2020). The informal e-waste recycling sector in Nigeria, often involving hazardous manual dismantling, exposes workers to severe health risks. Children are particularly vulnerable to the toxic fumes and materials prevalent in these informal recycling operations. The management of e-waste in Nigeria is further complicated by a lack of comprehensive regulations, limited awareness, and inadequate infrastructure for proper disposal and recycling. As a result, a significant portion of e-waste, including mobile phones, end up in landfills, dumpsites, or is illegally exported to other countries.

The aim of this study was to empirically examine the sources of phone waste generation in Makurdi, Nigeria and their final destination when it reaches its end of life. The objectives of the study were to identify the sources of phone waste generation in Makurdi LGA, appraise the existing structure of phone waste management in Makurdi LGA, and identify those engaged in phone waste management in Makurdi LGA.

Materials and Methods

The Study Area

The study was carried out in Makurdi LGA which is located in North-Central Nigeria, latitude 7° 33' 00" N to 7° 47' 00" N and longitude 8° 27' 00" E to 8° 4'00" E. The local government is bordered by Guma to the north, Gwer-east to the south, Gwer-west to the west and Doma local government area of Nassarawa State to the north-west (Figure 2). Covering 804 km2 land mass in a 20km radius circle, Makurdi became the capital of Benue state in the year 1976 following the division of Benue-Plateau into two distinct states (Isma'il and Kersha, 2018). Because of its centrality and high economic activity present, Makurdi serves not just as the capital of Benue state, but also as the administrative headquarter of Makurdi local government with 11 council wards (Agan, Ankpa, Bar, Clerks/Market, Central/South Mission, Fiidi, Mbalagh, Modern Market, North-bank 1, North-bank 2, and Wailomayo wards). The study area is one of the major cities and the main location of commercial activities, serving as a local trade center harboring majority of mobile phones traded and the corresponding e-wastes. According to the 2006 census of the National Population Commission, Makurdi had an estimated population of 300,377. This is below the Nigeria Metro Area Population estimates that the current metro area population of Makurdi in 2024 is 472,000 a 3.96% increase from 2023. The town covers an area of 800 km2. It started as a small river port in 1920s and gained prominence in 1927 when it became the headquarters of Benue Province.



Source: Ikyapa et al. (2022)

Figure 1: *Map of Makurdi Showing the Council Wards Visited*

Data Collection

Field Analysis:

The data for this study was collected from ten (10) council wards in Makurdi LGA of Benue State and included Agan, Ankpa, Bar, Central South Mission, Clerk Market, Fiidi, Modern Market, North Bank I, North Bank II, Wailomayo. A structured interview (also known as a standardized interview or a researcher-administered survey) was administered to 400 respondents to obtain quantitative information.

Statistical Analysis:

The data recorded were analyzed using SPSS version 19 while descriptive statistics were used to interpret the analyzed result.

Results and Discussion

Analysis of Responses to the Questionnaire

A total number of 400 respondents answered the semi-structured interview questions and the responses were meticulously analyzed and presented in the following charts in relationship with the research objective and research questions which sought to identify the sources of phone waste, the existing structure of phone waste management and those engaged in phone waste management in Makurdi, LGA.

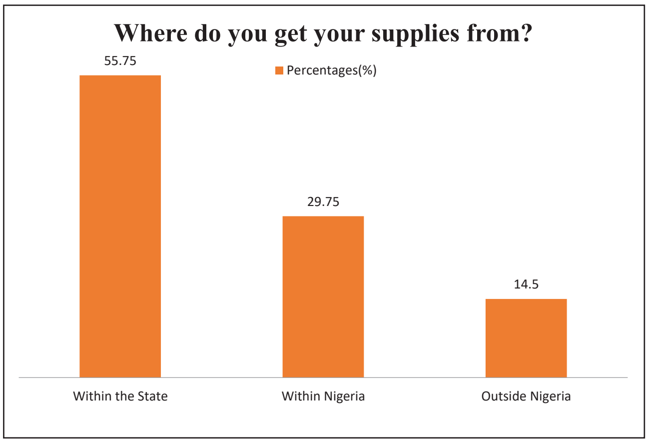


Figure 2: Responses on Sources of E-waste in Makurdi local government

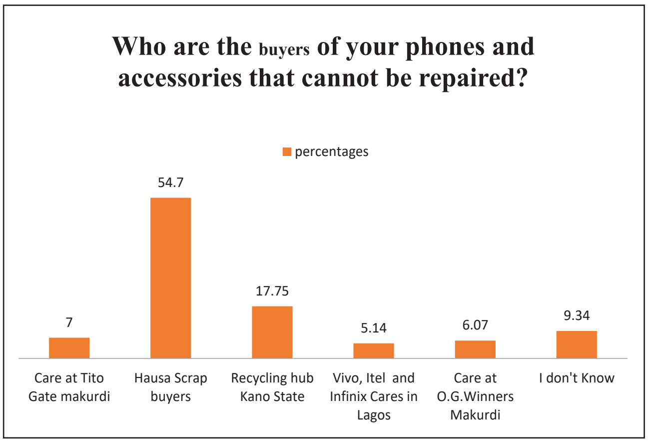


Figure 5: Responses on Buyers of E-waste in Makurdi local government

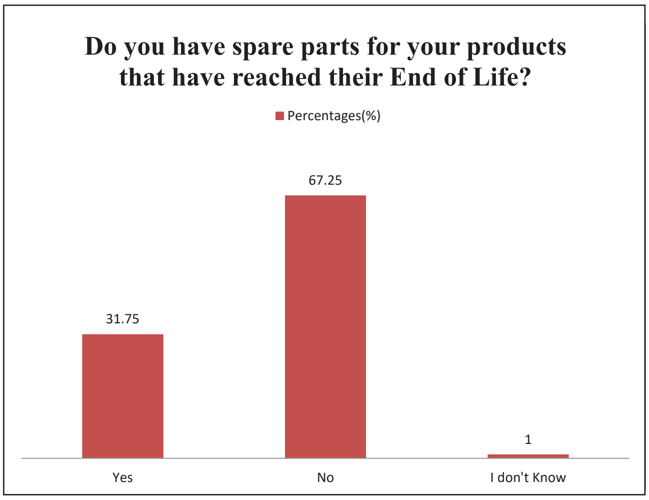


Figure 3: Responses on availability of E-waste in Makurdi LGA

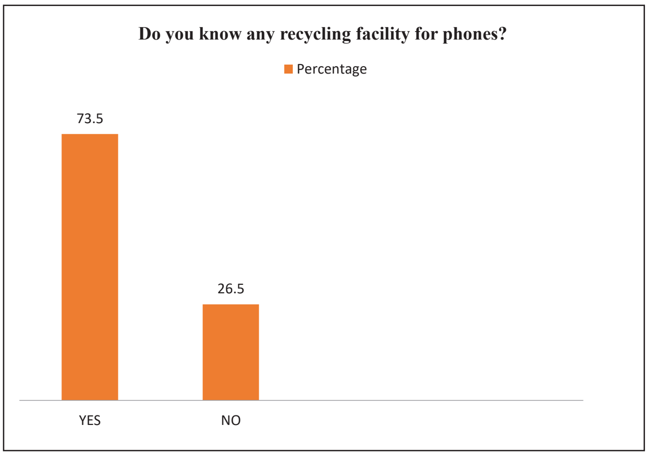


Figure 6: Responses on Mobile Phone-waste recycling facilities

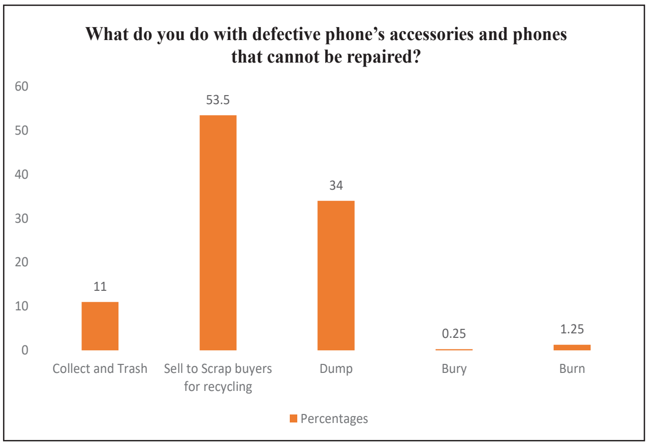


Figure 4: Responses on Disposal of E-waste in Makurdi LGA

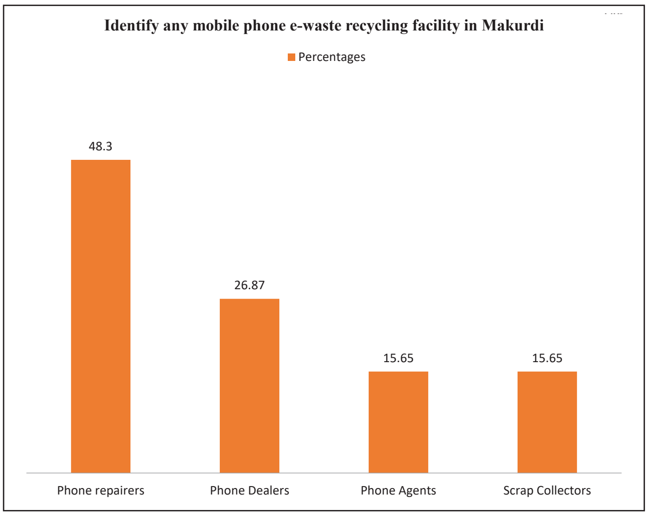


Figure 7: Identify any mobile phone-waste recycling facility in Makurdi

The rapid evolution of electronic devices and the 'throwaway' habit that is being cultivated around the globe ensures that this practice will continue for a long time except drastic and determined steps are taken to address the issue. For countries such as Nigeria who lack indigenous formal recycling plants, the prevalence of manual and informal recycling will continue to be one of the means of recycling e-waste thus exposing humans and the environment to poisonous chemicals inherent in decomposing electronic devices. As observed in the study, majority of the respondents attested that they source for the materials internally within the state. This finding contradicts with the popular notion that e-wastes are mainly imported into Nigeria (Greenpeace, 2018). However, the finding corresponds to the report by Kuehr, Hirsch, and Collins (2024) whose report in Global E-Waste Monitor, 2024 who posit that as technology advances, older devices like desktop computers, laptops, televisions, and audio systems become outdated and are often discarded and the rapid proliferation of smartphones has led to a high turnover rate, with old devices being replaced by newer models. For these reasons, older phone models are constantly discarded by the teeming population in Makurdi LGA. It is also found that e-wastes in Nigeria are imported from advanced nations, evidenced by the response from some dealers of the e-wastes materials particularly mobile phones who import them from outside the country into Nigeria which corresponds to the findings of (Okwu et al., 2022; Greenpeace, 2018). The findings from this inquiry revealed a rudimentary and informal system for managing mobile phone wastes. A significant portion of respondents indicated that when their mobile phones become obsolete or dysfunctional, they opt to sell them to recyclers. This practice, while seemingly contributing to a form of recycling, is often characterized by informal and unregulated processes that may pose environmental and health risks. Another common disposal method identified in the study was outright dumping of old mobile phones by both users and repair technicians. This practice is prevalent when individuals are unable to find buyers for their used devices. The indiscriminate disposal of phone waste in this manner exacerbates the environmental pollution problem and contributes to the accumulation of electronic waste in landfills and other unauthorized dumping sites (Ideho, 2012; Bimir, 2020; Okwu et al., 2022; Andeobu et al., 2023).

The reliance on informal recycling and the absence of a structured e-waste management system in Makurdi underscores the urgent need for interventions. The sale of mobile phones to recyclers, while appearing to be a solution, is often accompanied by substandard recycling practices that can lead to the release of hazardous substances into the environment. Moreover, the dumping of e-waste by users and repairers highlights the lack of awareness and concern about the environmental consequences of improper disposal (Nnorom et al., 2020; Okwu et al., 2022).

This corresponds to findings of Ideho, (2012), which could be attributed to the lack of environmental regulation or legal framework targeting e-waste as a special waste stream in Nigeria. There are existing laws that regulate the trans-boundary movement of toxic, hazardous and radioactive wastes and the achievement of environmentally sound management of hazardous substances. However, none is specific to the presence and management of e-waste.

The majority of mobile phone wastes in Makurdi is purchased by informal buyers, predominantly identified as Hausa scrap dealers indicates a significant reliance on the informal sector for e-waste management in the state. While some recycling activities occur within Makurdi, a considerable portion of the mobile phones collected, is transported to larger recycling hubs located outside the state such as Kano and Lagos. The export of phone wastes to other regions for recycling indicates a potential loss of valuable resources and economic opportunities for Benue State.

Despite the presence of some recycling initiatives in Makurdi, such as those operated by Care at Tito Gate and O.G. Winners Plaza, these facilities appear to be relatively small-scale and unable to handle the entire volume of phone wastes generated in the area. The unsold mobile e-waste which ends up being dumped indiscriminately imply significant contribution to environmental pollution and potential health hazards.

Conclusion

In conclusion, the discussion highlights how the rapid evolution of electronics and a pervasive "throwaway" culture have led to an overwhelming accumulation of e-waste in Nigeria. With the absence of formal recycling facilities, especially in regions like Makurdi, informal methods—such as manual recycling and indiscriminate dumping dominate. These practices, while providing some economic activity, expose communities and the environment to harmful chemicals and pollutants. Moreover, although some mobile phone waste is sourced internally, the importation of e-waste from advanced nations further complicates the issue. The findings underscore the urgent need for a comprehensive approach: establishing formal recycling centers, launching public awareness campaigns, implementing a targeted policy framework, engaging the private sector, and enhancing research efforts. Addressing these challenges is essential not only for safeguarding health and the environment but also for unlocking potential economic benefits from properly managed e-waste.

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APPENDIX: Phone e-waste

Scrap phones packed for movement to recycling centers

Phone screen guards dumped along the roadside

Dismantled scrap phones

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Structural (Physical) Attributes of Invasive Plant Species on Agricultural Land of Mangalpur, Chandrapur-01, Rautahat, Nepal.

Dharma Raj Sorali , Deepak Chhetry, Praveen Kumar Regmi
Tri-Chandra Multiple Campus
Correspondence: dharmasorali77@gmail.com

Abstract

Biological invasions are increasingly recognized as significant drivers of economic and environmental harm, largely due to their negative impacts on biodiversity and ecosystem processes. Understanding and quantifying the effects of Invasive Plant Species (IPS) on agricultural land has therefore become a key research priority to inform effective policy and management strategies. In this study, I surveyed agricultural land in Mangalpur village, Chandrapur Municipality-01, Rautahat district, Nepal, to assess the structural (physical) attributes of IPS and conducted a socio-economic survey to evaluate their impacts. Thirty 1×1 m² plots were established, and eight IPS belonging to four plant families were identified through cluster analysis. Key metrics such as density, frequency, abundance, cover, Relative Population Density (RPD), Relative Frequency (RF), Relative Abundance (RA), and Relative Cover (RC) were measured. Additionally, species richness, species diversity, and Importance Value Index (IVI) were calculated. The results revealed that three species Ageratum conyzoides, Argemone mexicana, and Erigeron karvinskianus were the most dominant IPS, with Ageratum conyzoides exhibiting the highest density. While local farmers are aware of the IPS problem, management practices such as manual removal, burning, chemical application, and ploughing are only occasionally implemented. This highlights an urgent need for more systematic and effective control measures, as the current level of invasion suggests the situation could worsen in the future if left unaddressed.

Keywords: *Agricultural land, Biological Invasion, IPS*

Introduction

Invasive Plant Species (IPS) are the species, native to one area or origin, that have been introduced into an area outside their natural distribution, either by accident or on purpose, and which have colonized or invaded their near habitat, threatening biological diversity, ecosystem, habitats and human well-being (CBD, 2002).

Biological invasions are continuously increasing in their spatial extent with a greater severity of impacts on the environment, agriculture, and livelihoods (Pejchar & Mooney, 2009; Simberloû et al. 2013; Paini et al. 2016). The number of invasive species continues to increase worldwide, and progress toward achieving the Convention on Biological Diversity's Aichi Target 9 remains unsatisfactory. Key gaps in current management efforts include insufficient early detection and rapid response systems, limited coordination among stakeholders, inadequate resources, and weak policy enforcement. Addressing these challenges is crucial for improving invasive species management and meeting global biodiversity goals (CBD, 2014; Seebens et al., 2017). Furthermore, Climate change exacerbates biological invasions by altering environmental conditions that favor the establishment and spread of invasive species, such as increased temperatures, altered precipitation patterns, and more frequent extreme weather events, which create new opportunities for invasions and reduce ecosystem resilience (IUCN, 2017; Bellard et al., 2013). Additionally, global trade accelerates the introduction and dispersal of invasive species by increasing the movement of goods and people across regions, often bypassing natural barriers and facilitating the transport of alien species to new habitats (Bellard et al., 2013; Tittensor et al., 2014). Together, climate change and trade act synergistically to intensify the scale and impact of biological invasions worldwide (Levine and D'antonio, 2003). Therefore, the management of invasive alien species, which is an essential component of biodiversity conservation and environmental management, has become a major challenge globally.

Nepal is ranked third out of 124 countries as one of the most threatened nations by biological invasions in the agriculture sector (Paini et al. 2016). Located in the center of the Himalayan biodiversity hotspot, Nepal has a steep elevation gradient, resulting in significant variations in topography and climate along its length. Extreme climatic variations refer to the wide range of temperature and precipitation conditions found across Nepal, from tropical lowlands to alpine highlands, creating diverse ecological niches (Shrestha et al., 2012). Invasive plant species, due to their high adaptability and phenotypic plasticity, can adjust their growth and reproductive strategies to thrive in these varied environments, allowing species from different bioclimatic regions to establish successfully (Bellard et al., 2013; Davidson et al., 2011). This adaptability makes Nepal's diverse climate particularly vulnerable to biological invasions. Furthermore, the probability of introduction of alien plant species to Nepal appears high due to 1) increasing tourism activities particularly in mountain regions, 2) growing amount and diversity of imported agricultural products, 3) increasing quantity of imported crop seeds and other commodities, and 4) ineûective bio-security eûorts including quarantine at international border points and airports. Recent studies indicate that the number of naturalized flowering plant species in Nepal has increased, with over 200 species now documented, and approximately 35 of these are recognized as invasive due to their significant ecological and economic impacts (Adhikari et al., 2021; Karki et al., 2023). Although the overall impact of biological invasions in Nepal has not been evaluated, the estimated annual cost of invasion to Nepal's agriculture sector alone is nearly US$ 22.7 million (Paini et al. 2016). Biological invasions in Nepal are increasingly threatening biodiversity and ecosystem services, with their severity and spread

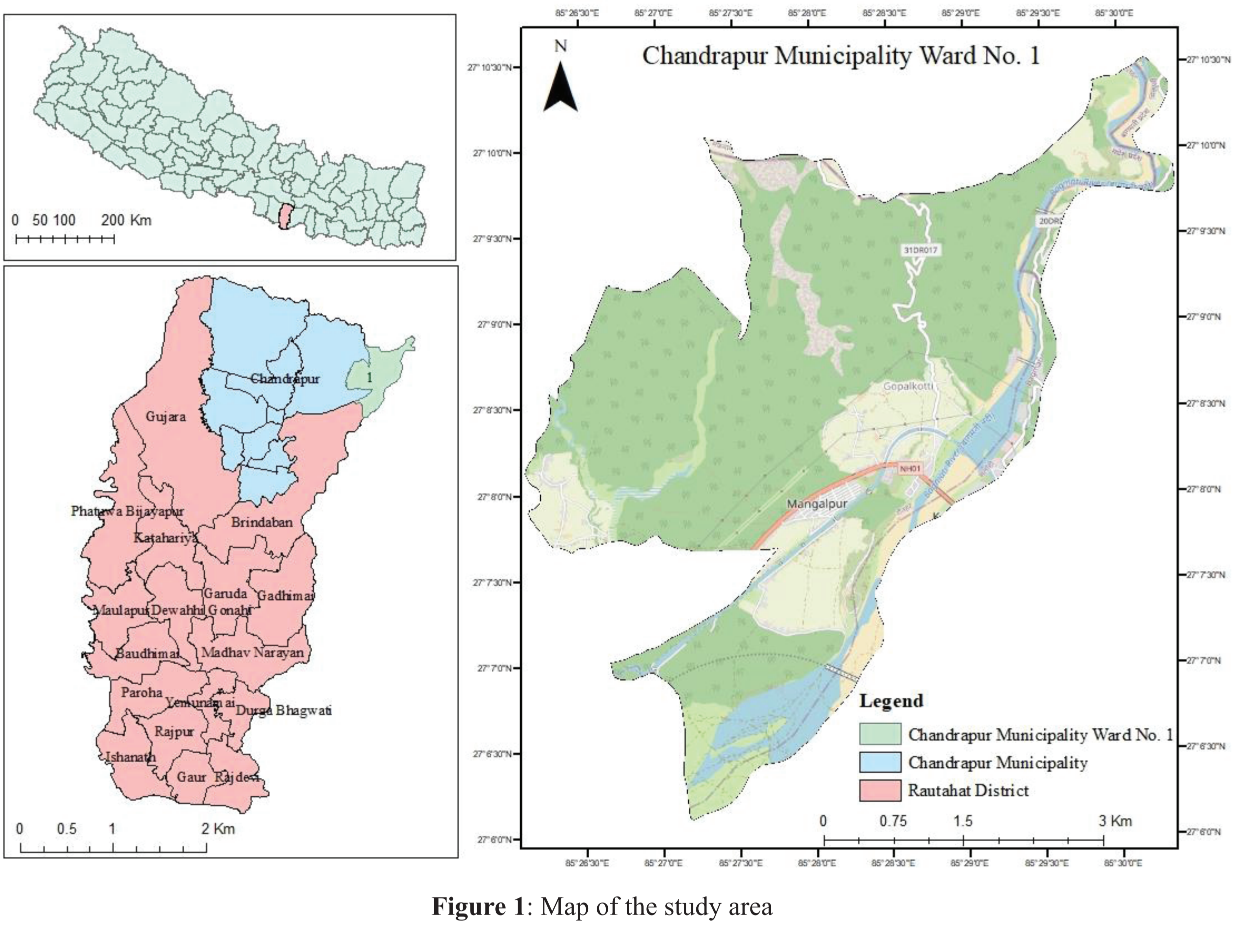

Figure 1: Map of the study area

continuing to grow (Bhatt et al., 2024; Shrestha et al., 2020). Invasive alien plant species degrade habitats, reduce native species diversity, and disrupt ecosystem functions, especially in protected areas and wetlands, driven largely by human activities such as agriculture and trade (Bhatt et al., 2024; Pant, Thapa, & Bist, 2023).

This study focused on assessing the structural attributes of Invasive Plant Species (IPS) in agricultural land of Chandrapur-1 (Mangalpur), Rautahat, Nepal. It aimed to measure population parameters such as density, frequency, abundance, cover, and Importance Value Index (IVI), evaluate the socio-economic impacts on local farmers, and develop management strategies based on the invasion mechanisms.

Materials and Method

Study Area

The study was conducted on Agricultural land of Mangalpur, Chandrapur-1 of Rautahat district, Madhesh Province, Nepal. The Agricultural land is located in 85.465965E and 27.123978N. The elevation of the study area is 136m from sea level. The Agricultural Land was selected because it is near to the human settlement and East-West Mahendra Highway. The study area is the source of the food grains, vegetables, fruits, lentils and other cash crops for farmers of the village. The area of the agricultural land is 50ha.

Field Survey

A Field Survey was carried out in January 2020. A preliminary assessment was carried out for rapport building with farmers of the village to get preliminary understanding about the status of the selected Agricultural land. A general approach of the preliminary survey was to get the field information from farmers of the Mangalpur village.

Plot Sampling and IPS

In the Agricultural land (mixed crops land), 5 transect were made and in each transect 6 plots of size $1 \times 1m^2$ were sampled to measure selected IPS density, frequency, abundance and cover. The length of transect was about 100m and distance between them was about 50m. The distance between two plots was 10m. Sample size $1 \times 1m^2$ was made in Agricultural land. The Geographic location (latitude, longitude and elevation) was noted by the Global Positioning System (GPS). Invasive Plant Species cover was estimated visual estimation in percentage cover (1%, 2%, 5% and increments up to 100%) in each plot. The Invasive Plant Species reported were collected and counted by separating their individual root. The IPS were identified using Final Manual on Invasive Plant Species in Kailash Sacred Landscape-Nepal (2016), comparing herbaria of Tribhuvan University Central Herbarium, (TUCH), Kirtipur, Kathmandu, Nepal.

Density, Frequency, Abundance and Cover of IPS

After recognizing plant communities by using Final Manual on Invasive Plant Species in Kailash Sacred Landscape-Nepal (2016), comparing herbaria of Tribhuvan University Central Herbarium, (TUCH), Kirtipur, Kathmandu, Nepal and IPS cover, density and frequency of all the IPS found on Agricultural land of Mangalpur village were measured. Population density, frequency, abundance, and cover of Invasive Plant Species (IPS) were measured.

Population density, Frequency, Abundance, and Cover were calculated by the following formulas,

$$PD = \frac{\text{Mean no. of individual of each species}}{\text{Area of Quadrate in m}^2}$$

$$\text{Frequency (\%)} = \left(\frac{\text{No. of quadrats in which a species occurs}}{\text{Total no. of quadrats of occurrence}}\right) \times 100\%$$

$$\text{Abundance} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of quadrats of occurrence}}$$

$$\text{Cover (\%)} = \left(\frac{\text{Sum of cover of IPS from all quadrate}}{\text{Total no. of plot sampled}}\right) \times 100\%$$

(Source: Zhigila et al. 2015)

Socio-economic Survey

A set of structured questionnaires was prepared to gather qualitative information on invasive plant species (IPS) in the study area. Key Informant

Interviews were conducted in Mangalpur and Dovantol villages of Chandrapur-01 Municipality, Rautahat district, involving both elderly and younger farmers. A total of 10 farmers were interviewed as key informants using a judgmental sampling method, while an additional 60 farmers were surveyed to collect broader information about IPS. The questionnaire focused on farmers' awareness of IPS, the common invasive species present, their impact on crop productivity, control methods employed, and challenges faced in managing these species. The purpose was to understand local knowledge and perceptions, assess the ecological and economic effects of IPS, and identify effective management practices within the community.

Results

Plant Species Richness

In the study area, the species richness of invasive plant species (IPS) increased annually, indicating rapid growth and a negative impact on agricultural land and crop production. A total of eight IPS belonging to four families were recorded (Table 1), with Asteraceae being the richest family containing four species. Among them, *Ageratum conyzoides*, *Argemone mexicana*, and *Erigeron karvinskianus* were the most dominant and problematic species affecting the crop fields.

Invasive Plant Species (IPS)

In the Agricultural land, following IPS were found:

Table 1: List of IPS found in the Agricultural land

S.N.	Scientific name of IPS	Common name	Local name	Family
1	*Ageratum conyzoides*	Billygoat weed	Gandhe Jhar	Asteraceae
2	*Erigeron karvinkianus*	Karwinsky's Fleabane	Phule Jhar	Asteraceae
3	*Amaranthus spinosus*	Spiny pigweed	Kandlude	Amaranthaceae
4	*Oxalis latiofola*	Purple wood sorel	Chari Amilo	Oxalidaceae
5	*Parthenium hysterophorus*	Parthenium	Pati Jhar	Asteraceae
6	*Alternanthera philoxeroides*	Alligator weed	Jala jambhu	Amaranthaceae
7	*Agremone mexicana*	Mexican poppy	Thakal	Papaveraceae
8	*Bidens pilosa*	Cobbelers pegs	Suere Kuro	Asteraceae

Cover of IPS in the Agricultural land

A total of eight invasive plant species (IPS) were identified in the agricultural land during the study. Among these species, *Ageratum conyzoides* exhibited the highest cover, indicating its widespread dominance in the area. This was followed by *Argemone mexicana*, *Bidens pilosa*, and *Erigeron karvinskianus*, which also showed significant coverage but to a lesser extent. In contrast, *Alternanthera philoxeroides* was recorded with the lowest cover among the IPS, suggesting a relatively limited presence in the agricultural fields. The cover measurements were obtained through systematic sampling using quadrats, providing quantitative data on the spatial extent of each species within the study site.

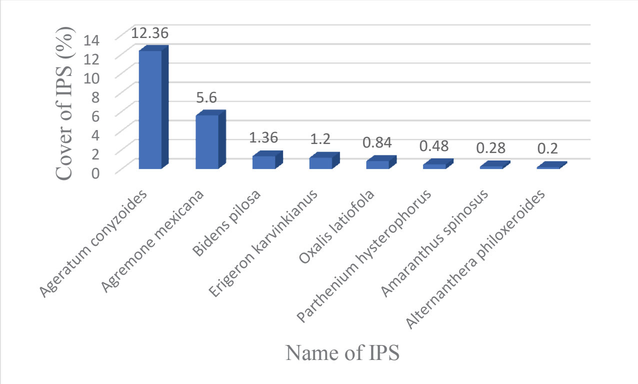

Figure 2: Cover of IPS

Population density, Frequency, Abundance, RPD, RF, RA, RC, and IVI of IPS

Table 2: Calculation of population density, frequency, abundance, cover, RPD, RF, RA, RC, and IVI of IPS

S.N.	Name of species	Total no. of individuals of each species on Agricultural land	Mean no. of individuals of each species	Total no. of Quadrats of occurrence	No. of Quadrats occurrence	Population density of each species (Ind./m²)
1	*Ageratum conyzoides*	309	0.554	30	22	0.554
2	*Erigeron karvinkianus*	30	0.054	30	11	0.054
3	*Amaranthus spinosus*	7	0.013	30	6	0.013
4	*Oxalis latiofola*	21	0.038	30	2	0.038
5	*Parthenium hysterophorus*	12	0.022	30	1	0.022
6	*Alternanthera philoxeroides*	5	0.009	30	3	0.009
7	*Agremone mexicana*	140	0.251	30	18	0.251
8	*Bidens pilosa*	34	0.061	30	8	0.061
	Total	**558**				**ΣPD=1**

Abundance of each species (A)	Frequency of each species (F) (%)	Cover of each species (C) (%)	Relative Population Density (RPD) (%)	Relative Abundance (RA) (%)	Relative Frequency (RF) (%)	Relative Cover (RC) (%)	IVI (%)
14.05	73.33	12.36	55.38	25.95	30.98	55.38	112.31
2.73	36.67	1.2	5.38	5.04	15.49	5.38	25.91
1.17	20	0.28	1.25	2.16	8.45	1.25	11.86
10.5	6.67	0.84	3.76	19.39	2.82	3.76	25.28
12	3.33	0.48	2.15	22.17	1.41	2.15	25.73
1.67	10	0.2	0.89	3.08	4.23	0.89	8.20
7.78	60	5.6	25.09	14.37	25.35	25.09	64.81
4.25	26.67	1.36	6.09	7.85	11.27	6.09	25.21
ΣA=54.13	**ΣF=236.67**	**ΣC=22.32**					

Socio-economic Impact of IPS

Key informants identified several invasive plant species (IPS) as major problems in agricultural lands, notably *Oxalis latifolia*, *Argemone mexicana*, and *Ageratum conyzoides*. These species have been observed to negatively impact native plants and reduce the productivity of food grains, vegetables, lentils, spices, and fruits. The invasion of IPS has become increasingly severe, leading to a decline in crop yields and threatening the livelihoods of farmers and villagers who depend on these lands for food and income. Specifically, *Ageratum conyzoides* reduces plant diversity and biomass, while *Argemone mexicana* releases allelochemicals that inhibit the germination and growth of important crops like beans and maize.

Farmers are actively trying to control these invasive species through physical methods such as uprooting, pulling, and burning, as well as by applying chemical pesticides like trafajin and 2,4-D. However, these control measures are often labor-intensive and may not provide long-term solutions. Many farmers expressed concern about the future impact of IPS on their agro-ecosystems, fearing further declines in crop yields and increased difficulty in managing their land. The consensus among respondents is that if the invasion continues unchecked, it could severely jeopardize food security and the sustainability of agricultural practices in the region.

Discussion

Plant Species Richness

The increasing species richness of invasive plant species (IPS) in the study area, with eight species from four families—especially the Asteraceae family—reflects similar trends reported in other agricultural regions (Sharma, Singh, & Verma, 2020). Notably, *Ageratum conyzoides*, *Argemone* *mexicana*, and *Erigeron karvinkianus* were the most dominant and problematic species, consistent with findings by Singh and Kumar (2018), who documented their negative effects on crop yields and native biodiversity. The year-by-year growth of IPS and its impact on reducing crop production aligns with Mwangi, Muthuri, and Wanjiru's (2019) observations that invasive plants alter soil nutrients and outcompete crops. Additionally, the allelopathic nature of species like *Ageratum conyzoides* further suppresses crop growth (Kumar & Joshi, 2017), highlighting the urgent need for effective management to protect agricultural productivity.

Impacts of IPS on Species Richness

The increasing invasion of species like *Ageratum conyzoides* and *Argemone mexicana* in agricultural lands reduces native species richness and crop yields, as also reported by Zhang et al. (2023), who found that invasive plants disrupt native plant communities and soil health. High density and dominance of these IPS negatively affect biodiversity and productivity, consistent with findings by Lee and Park (2022) on agroecosystem degradation due to invasive weeds. Farmers' efforts to control IPS through physical and chemical means reflect global challenges in managing invasions that threaten food security and ecosystem stability (Garcia et al., 2021). These impacts highlight the urgent need for integrated management to protect native diversity and sustain agriculture.

Socio-economic Impact of IPS

Agricultural ecosystems in the study area are highly susceptible to invasive plant species (IPS), with key informants and farmers identifying *Ageratum conyzoides*, *Argemone mexicana*, and *Erigeron karvinkianus* as major threats to their livelihoods. Despite awareness of IPS invasion, local management efforts remain limited and sporadic, relying mainly on manual uprooting, burning, chemical application, and ploughing, which have proven insufficient to significantly reduce IPS spread. This situation mirrors findings by Johnson et al. (2022), who reported that inadequate and inconsistent control measures in rural agricultural communities often fail to contain invasive species, exacerbating socio-economic losses. Rejmánek (2005) emphasizes that effective invasive species management requires a comprehensive approach including prevention, early detection, eradication, and integrated control, with prevention being the most cost-effective strategy. These insights highlight the urgent need for coordinated local initiatives and policy support to implement integrated management practices that can mitigate the socio-economic impacts of IPS on farming communities.

Conclusion

Invasive plant species (IPS), notably *Ageratum conyzoides*, *Argemone mexicana*, and *Erigeron karvinkianus*, are increasingly encroaching upon agricultural lands, causing marked declines in native species richness, crop yields, and soil health. This pattern is consistent with extensive research showing that IPS disrupt native plant communities and agroecosystem functions, thereby threatening food security and the livelihoods of farmers (Zhang, Chen, & Wu, 2023; Kumar & Joshi, 2017). Although local farmers employ control measures such as manual removal, burning, and chemical treatments, these efforts have generally been inadequate in effectively managing IPS, mirroring challenges faced in rural agricultural systems worldwide (Johnson, Lee, & Patel, 2022; Mwangi, Muthuri, & Wanjiru, 2019).

The socio-economic consequences of IPS invasion—including reduced agricultural productivity and increased labor demands—highlight the pressing need for integrated and proactive management strategies. Emphasizing prevention, early detection, and coordinated control remains essential to curbing IPS spread, as underscored by Rejmánek (2005). Enhancing local management initiatives through policy support and sustainable practices will be vital to conserving native biodiversity and maintaining agricultural productivity over the long term. Without such comprehensive approaches, continued IPS proliferation is likely to worsen ecological degradation and deepen socio-economic challenges for farming communities.

Recommendations

- Future management of invasive plant species should utilize integrated methods combining mechanical, chemical, biological, and cultural controls tailored to local conditions.
- Prevention efforts must be strengthened through community engagement, early detection, and effective biosecurity measures.
- Supportive policies, sustained funding, and continuous research are vital to empower stakeholders and promote ecosystem restoration and resilience.

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The Current Status and Composition of Bio-Medical Waste Management in Narayani Hospital of Birgunj Metropolitan City

Pradip Shah*, **Praveen Kumar Regmi**
Department of Environmental Science and Management, School of Environmental Science and Management, Kathmandu, Nepal
Correspondence: Shahpradip562@gmail.com

Abstract

The biomedical waste generated during treatment, immunization of human or animals, diagnosis, laboratory activities from Narayani hospital and other medical center in the Birgunj Metropolitan City become a serious public and environmental concern. Therefore, the general objectives of the study are to identify the current status and practices of bio-medical waste management with specific objectives to find out the status and composition of bio-medical waste and to access the method of management in Narayani Hospital and other also. The simple random sampling technique used to collect data from Narayani hospital and 50 responses on the day of one week. The study showed total biomedical waste generation rate is 48kg/day and 0.16 kg/bed/day. Generally, generated biomedical waste were Vials, Syringe, Saline bottle, Gloves, Cardboard box, Plastic Wrapper, Intravenous Set and Cotton gauge. The result showed, there are 36 hospitals with 2500 beds in Metropolitan city from which 54.92 tons/year of Intravenous set, 21.89 tons/year of Vials, 1.64 tons/year of plastic wrapper, 8.65 tons/year of Cotton gauge, 10.08 tons/year of syringe, 20.02 tons/year of saline bottles, 8.78 tons/year of gloves and 19.79 tons/year of Cardboard box generated from entire hospitals. Similarly, from entire hospital 0.43 tons/day, 3.00 tons/week, 13.02 tons/month and 156.19 tons/year of recyclable biomedical waste generated. In case of disposal and management approach 88 percent respondents to collect waste in dustbin and 12 percent in Polyethene bags. Hence, it concluded segregation, collection, transportation, storage, disposal and management practice of the biomedical waste was found satisfactory.

Keywords: *Biomedical Waste, Collection, Segregation, Transportation, Disposal*

Introduction

The generation of medical waste by healthcare facilities has grown drastically and become a serious public and environmental concern around the globe. According to World Health Organization (WHO, 2018) said that approximately 85% of biomedical waste are non-hazardous, around 10% are infectious and 5% are hazardous wastes. The biomedical waste is categorized as Human anatomical waste (human tissues, organs, body parts), Microbiology & Biotechnology waste (wastes from laboratory cultures, glass slides, stocks or specimens of microorganisms), Sharps waste (needles, syringes, scalpels, blades, glass etc.), Solid waste (blood contaminated cotton, dressings, soiled plaster casts, lines etc.), Liquid Waste (body fluids, laboratory and washing, cleaning, house-keeping and disinfecting activities) and discarded medicines and cytotoxic drugs (Lakshmi Bhaskar et al., 2020*)*.

After Birgunj became a metropolitan city, an influx of migrants and ward mergers increased the city's population load. Better healthcare services, education, infrastructure, connectivity, and drinking water have drawn many visitors as well as citizens from the surrounding region. Birgunj Metropolitan City has 36 hospitals, according to statistics published by the Metropolitan City Public Health Section. Among 36 private hospitals, the Narayani Central hospital is the only public hospital that provides various medical services to people. The generated medical wastes are directly kept on roadsides, dump on backyards, through on public places, discharge on drainage, open burning and so on. A major issue related to current biomedical waste management in public and private hospitals is that the implementation of biomedical waste regulation is unsatisfactory as some hospitals are disposing of waste in a haphazard, improper and indiscriminate manner in the Birgunj Metropolitan City. In metropolitan, lack of segregation practices results in mixing of hospital wastes with general waste making the whole waste stream hazardous (Department of Health and Forest, Environment and Disaster Management of Birgunj Metropolitan City).

Biomedical waste management has become a critical challenge for health institution, hospital and local body, due to a lack of adequate infrastructure and technology. The inappropriate disposal of hospital waste causes a wide range of issues in the community and spreads various infectious diseases. As a result, the proposed study is précised general as well as specific goal as, to identify the current status and practices of bio-medical waste management in Narayani hospital of Birgunj Metropolitan City, to find out the status and composition of bio- medical waste and to access the practices and method of bio- medical waste management.

Material and Methodology

Study Area

There are 35 private and only one public hospital in Birgunj Metropolitan City (Department of Health of Birgunj Metropolitan City., 2024). The Narayani Hospital is only the public hospital of metropolitan city situated in ward 03 and 04 considered as study area. From geographical point of view, Narayani Hospital covers the region between the northern latitude of 27° 0'14.19"N - 27° 0'14.45"N and the eastern longitude of 84°52'15.82"E - 84°52'18.42"E. The altitude ranges from 108 meters to 110 meters above the sea level.

The Narayani hospital is government hospital from which the collection of data and other document is easy and it also consist of huge number of patients with various department. The hospital is situated in ward no 3 and ward no 4 of metropolitan city, which consist of 7604 population in ward no 3 and 3285 population in ward no 4. Mostly population in these wards are employed in various sector. The population of these wards are highly depended and harvesting the medical facilities from the Narayani hospital. Also, there are various medical center in these wards. However, the Narayani hospital is the affordable service provided hospital with various medical facilities to both for poor and rich people. As, theses wards are highly developed in the metropolitan city, most of the people receiving the medical services from Narayani hospital. Therefore, it is selected as suitable for the study.

Nature and Source of Data

The current study is based on primary and secondary data gathered through a field survey of the selected hospital and surrounding area. The primary data contained key informant data and an interview plan to acquire the essential data. The secondary sources of data were obtained through the usage of related books, journals, periodicals, and other references linked to the study's topic.

Sample Size and Sampling Procedure

Only Narayani Hospital selected for study in which 50 responses, 25 from inside the hospital from different department and 25 around the hospital area were chosen on the day of one week of sampling from patients and general public (Prakash Awasthi et al., 2023 & ADB, 2013). The one week of biomedical waste collection volume were taken for the study. The biomedical waste was kept in color dustbin in each ward and from ward waste were collected manually by worker at morning and evening. The biomedical waste transported by trolly in storage center. In the storage center waste segregated to identified the composition and each component was weighing by digital spring balance and digital balance in each day of one week. Some of the biomedical waste such as syringe and vials weighted at same time of collection in ward.

Techniques and Tools of Data Collections:

The primary and secondary data used to complete the study. The researcher obtains 50 primary data from respondents in one week duration of the sampling by using the approaches as below.

Questionnaire and Consultation:

Structured questionnaire used for gathering the real and accurate data about the collection and

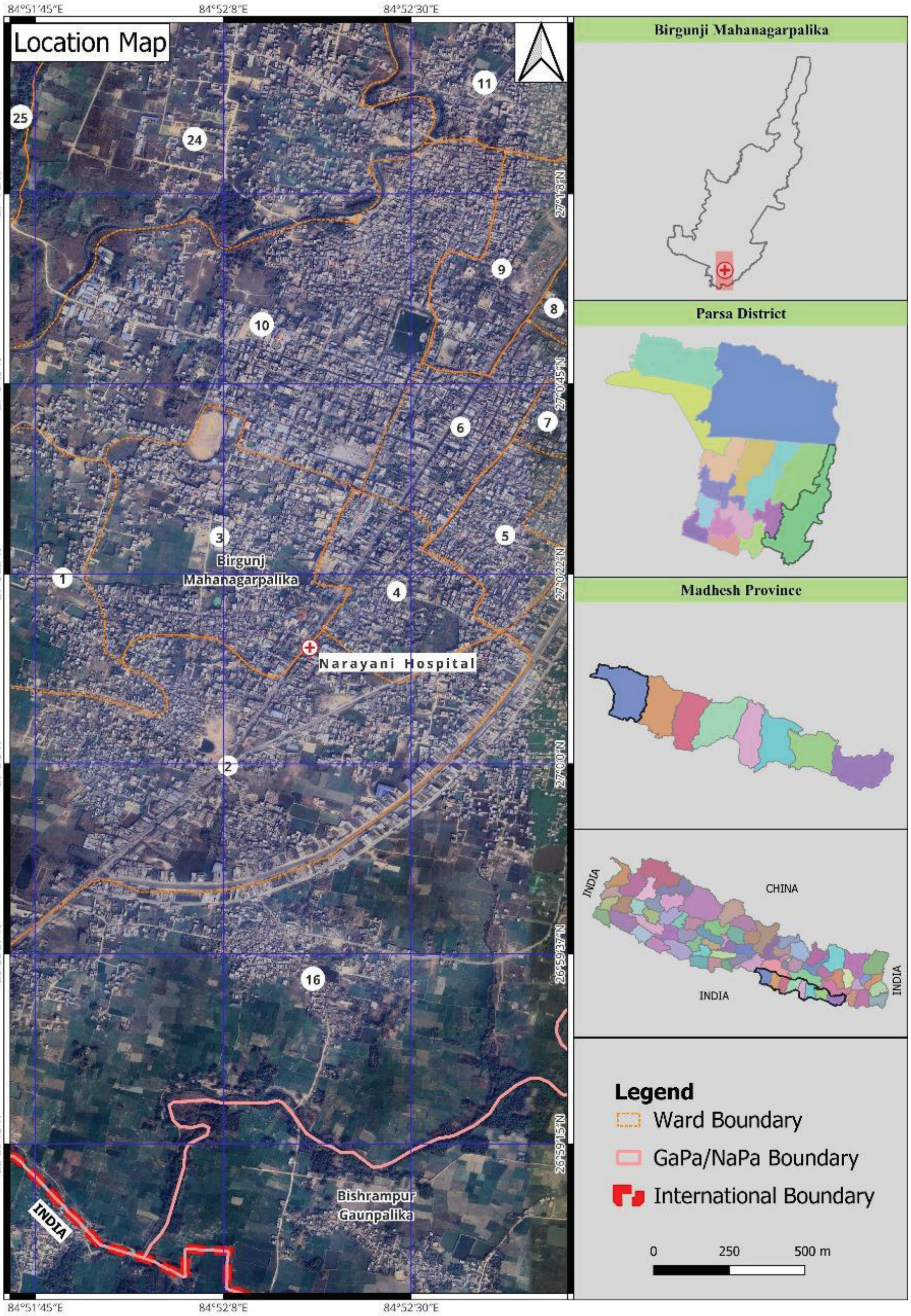

Figure 1: Location Map of the study area

management practices of biomedical waste from Narayani Hospital by survey of patients and general public.

Key Informant Interview:

The primary data was gathered from 10 key informants via semi- or unstructured interviews to get essential data for bio-medical waste collection and management. The interview is used to cross-check data acquired from the questionnaire. To gather essential information from key informants such as the hospital management committee, worker leader, department head, local leader, and stakeholders, interviews were conducted.

Field Visit:

From the field visit, observations were made to capture problems in the ground and to take photographs. Such images were used to assess, the major healthcare issues and waste production and the current management of healthcare waste.

Data Analysis

In this study Statistical Package for the Social Sciences (SPSS) and Microsoft Excel used for arranging the data, data analysis, plotting of graph and bar diagram.

Result and Discussion

Types of Biomedical Waste Generated by the Hospital

According to Department of Health, in the metropolitan, there are so many private hospitals, clinic, diagnostic center, health post but Narayani is the only largest hospital which serve 300 beds along with 19 departments and 9 wards recently. It serves 1000- 1200 residents/days, 23,290 outdoor patients/months, 1,353 indoor patients/months and 600-900 outdoor patients per day. The total biomedical waste generation rate is 48 kg/day and 0.16 kg/bed/day. The hospital appointed 10 workers and 3 categories of color-coding dustbins to collect segregated waste from each ward and disposal into waste management center of the hospital. Generally, the generated biomedical waste were Vials, Syringe, Saline bottle, Gloves, Cardboard box, Plastic Wrapper, Intravenous Set (IV Set) and Cotton gauge.

Vials:

A vial is a small glass or plastic vessel which is often used to store medication in the form of liquids and powders. In the medical ward the average high volume of vials recorded as 1.13 kg/day followed by Laboratory 1.07 kg/day and ICU 0.97 kg/day. In the NICU the volume recorded as 0.04 kg/day and Radiology 0.07 kg/day as the least. The figure 2 showed generation of Vials in kg/day from different ward.

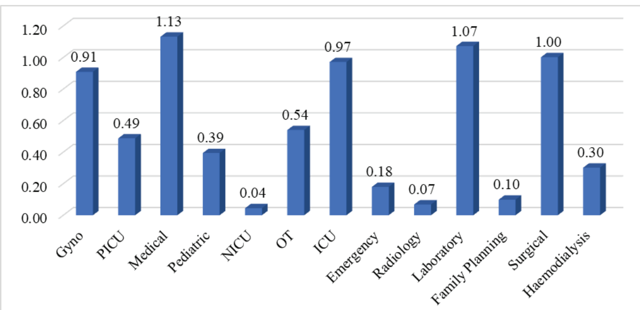

Figure 2: The average rate of Vials in kg/day from different ward

Syringe:

The result showed maximum volume of 0.95 kg/day of syringe generated from laboratory ward followed by medical ward 0.38 kg/day. The minimum volume of syringe recorded from Radiology 0.05 kg/day. According to the study, Radiology department consist of CT- Scan, MRI, X-rays and Ultra-Sound and syringe are only used in MRI for injecting gadolinium-based contrast agents, which is 4-5 number discarded regularly. Therefore, the volume of syringe recorded minimum. The average rate of Syringe in kg/day generated from different ward shown in figure 3.

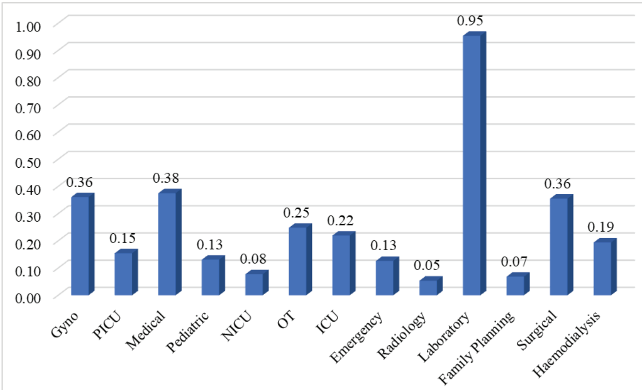

Figure 3: The average rate of Syringe in kg/day from different ward

Saline Bottle:

The saline bottle is container that hold a mixture of sodium chloride and water has number of uses such as treatment of electrolytic imbalance, cleaning of wounds, removal and storage of contact lenses and so on. In the Narayani hospital, Gyno ward generated maximum volume 1.64 kg/day of saline bottles and minimum 0.01 kg/day in NICU. Some of the ward such as Radiology and Laboratory there were no any production of saline bottles. Similarly, the interview with ward In-charge of PICU, Pediatric, NICU and Family planning generation of saline waste in maximum volume in winter season then summer. In winter, the high rate of patients recorded with various kinds of diseases. The figure 4, showed average rate of Saline Bottle in kg/day from different ward.

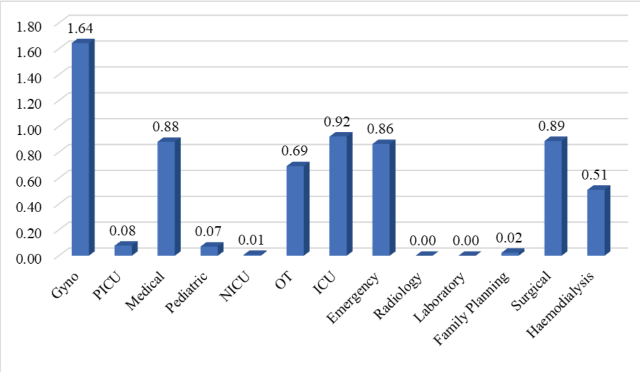

Figure 4: The average rate of Saline Bottle in kg/day from different ward

Gloves:

Medical gloves are personal protective equipment used to protect from the spread of micro-organisms, infectious materials, radioactive materials and chemicals that may potentially cause infection or illness during medical procedures and examinations.

The study showed maximum volume of gloves generated from Haemodialysis 0.56 kg/day and 0.53 kg/day from Operation Theater. In the NICU less amount recorded as 0.01 kg/day. The maximum average number of patients 16 per/day recorded in Haemodialysis increased maximum amount of gloves generation. On the other hand, NICU the newly born baby recorded as 6 per/day and according to Preece et al., 2020 latex gloves are the fact of irritating allergic reaction even in 6% of the worldwide population reduced in maximum generation of gloves. The Figure 5 showed average rate of Gloves generation in kg/day from different ward.

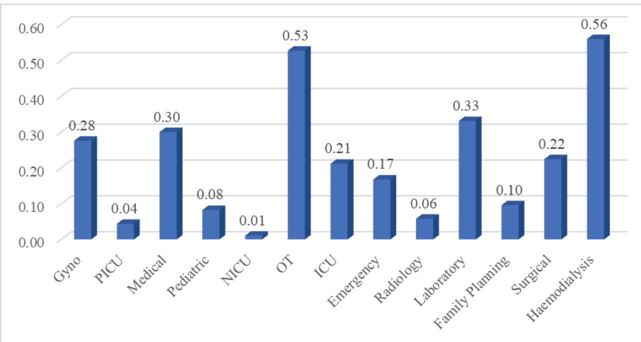

Figure 5: The average rate of Gloves in kg/day from different ward

Cardboard Box:

The cardboards are generally produced as byproduct of material used to package gloves, syringe, medication and pharmaceuticals. According to study, the high volume recorded 2.01 kg/day from Operation Theater followed by Haemodialysis 0.98 kg/day. Some of the ward such as Family planning 0.10 kg/day, PICU 0.11 kg/day and Radiology, NICU had zero generation showed least production. The Figure 6 exposed average rate of Cardboard box generated in kg/day from different ward.

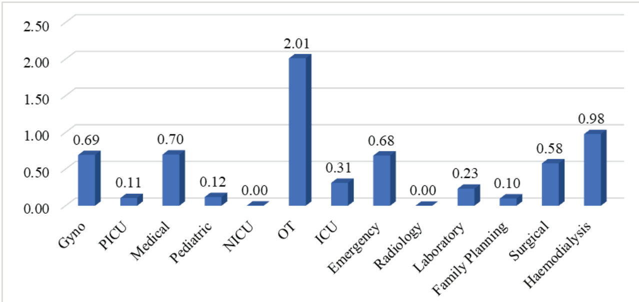

Figure 6: The average rate of Cardboard box in kg/day from different ward

Plastic Wrapper:

Plastic wrappers are mainly generated from syringes, gloves, catheters, medication bottles and other medical items. From figure 16, the Gyno ward generated maximum volume of plastic wrapper 0.095 kg/day and minimum 0.014 kg/day from family planning. The Radiology and NICU wards had zero production of plastic wrapper. The figure 7 showed average rate of Plastic wrapper production in kg/day from different ward.

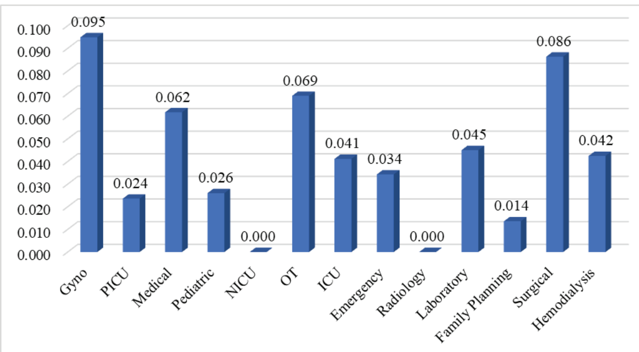

Figure 7: The average rate of Plastic wrapper in kg/day from different ward

Intravenous Set (IV set):

The intravenous set is primarily used to deliver various fluids, medication, nutritional support, blood transfusion and removal of fluids from the body. Generally, haemodialysis wards the average number of patients 16 recorded maximum rate of intravenous set 16.94 kg/day along with medical and gyno ward 0.26 kg/day simultaneously.

In the family planning wards 0.01 kg/day generation of average number of patient 3 per/day showed low and volume increased in winter season with increase in number of patients. Similarly, in surgical ward, the average number of patients recorded 28 per/day transferred in medical ward along with intravenous set revealed minimum generation of intravenous set 0.01 kg/day also. In laboratory and radiology ward there was no any production of intravenous set. The figure 8 showed average rate of Intravenous set-in kg/day from different ward.

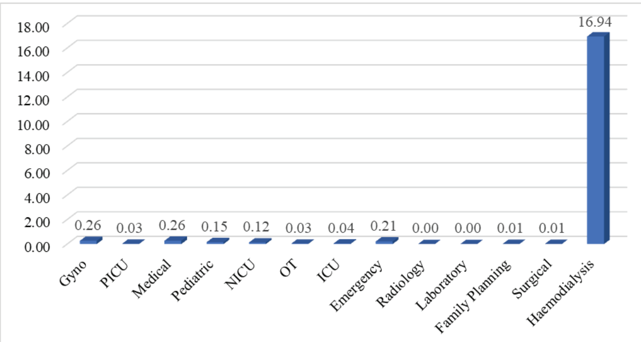

Figure 8: The average rate of Intravenous set-in kg/day from different ward

Cotton Gauge:

The cotton gauge is a purely cotton made material used for cleaning the wounds, injury, cuts and for absorbing body fluids and liquids. The study showed maximum rate of cotton gauge generated from Operation theater 1.63 kg/day followed by gyno 0.48 kg/day. Whereas, the minimum volume 0.04 kg/day recorded in Laboratory, Pediatric and PICU. The figure 9 showed average rate of Cotton Gauge generation in kg/day from different ward.

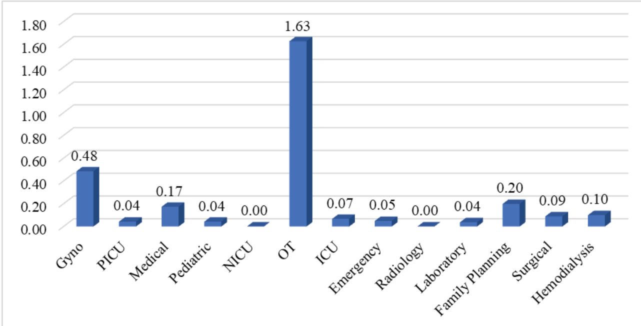

Figure 9: The average rate of Cotton Gauge in kg/day from different ward

Volume of Different Kind of Bio-medical Waste

There are various kinds of biomedical waste generated from hospital such as Vials, Syringe, Saline Bottles, Gloves, Cardboard, Plastic Wrapper, Intravenous sets, Cotton Gauge, Body parts, fluids and liquid waste. According to the study, there are 36 hospitals with 2500 beds in Metropolitan city in which Narayani Hospital is one, there Intravenous set were maximum volume 6.59 tons/year and Vials 2.63 tons/year of biomedical waste generated and in other metropolitan hospitals 54.92 tons/year and 21.89 tons/year respectively.

Similarly, the plastic wrapper 0.20 tons/year followed by Cotton gauge 1.04 tons/year in Narayani hospital and 1.64 tons/year and 8.65 tons/year in entire hospital of metropolitan city recorded as the least. The figure 10 showed average volume of different kinds of biomedical waste generated from Narayani Hospital in tons/year and figure 11 presented average volume of different kinds of biomedical waste generated from Metropolitan City Hospitals in tons/year.

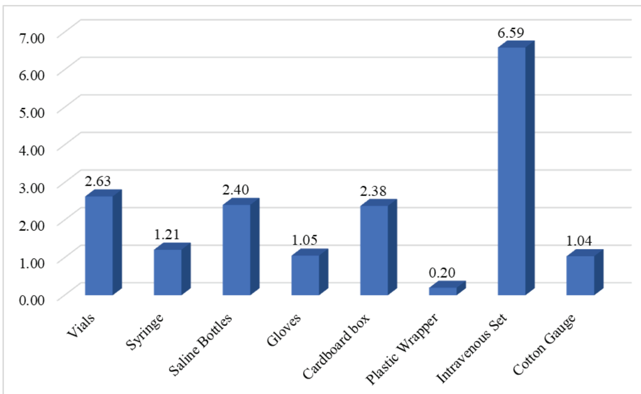

Figure 10: The average volume of different kinds of Biomedical waste generated from Narayani Hospital in tons/year

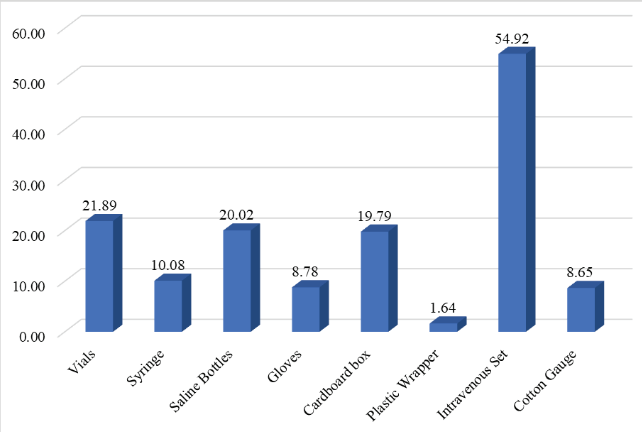

Figure 11: The average volume of different kinds of Biomedical waste generated from Metropolitan City Hospitals in tons/year

Biomedical Waste Generated from the Department

As the hospital is the largest hospital with 9 ward with 300 beds and serving 24,643 and 2, 75,625 patients monthly and annually. Each of the wards has fluctuated in number of patients so that generation rate and types of biomedical waste fluctuated. According to the study, the high rate of biomedical waste generated from Dialysis ward 19.62 kg/day followed by Operation theatre 5.74 kg/day and Gyno 4.72 kg/day. Similarly, Radiology recorded as 0.18 kg/day lowest generation rate followed by NICU 0.26 kg/day and Family Planning 0.60 kg/day. The generation of biomedical waste from different wards kg/day is mention below in figure 12.

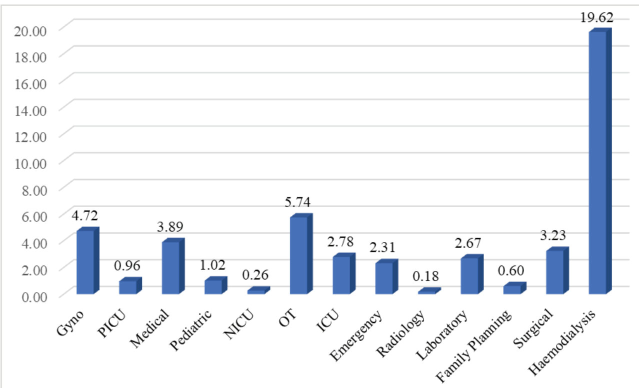

Figure 12: The average volume of Bio-medical waste in kg/day from different ward

Biomedical Waste Collection and Transportation Practices

In Nepal, According to guidelines (DoHS, 2014) for biomedical waste collected in designated storage area and transported in closed vehicles on a regular basis before treatment and removal. The collection and storage areas should be located away from patient rooms, laboratories, hospital function/ operation rooms or any public access area (DoHS, 2014).

The study survey in Narayani hospital showed, biomedical and organic waste from different wards collected in three kinds of dustbin (Red, Blue & Green Color). Some of the high toxic and contaminated waste such as syringe and vials collected in dustbin (Red color) wrapped with polyethene bag and remaining such as saline bottles, cotton gauge, cardboard box, plastic wrapper, intravenous set directly kept in dustbin (Blue color) and organic waste in green color dustbin. The removal of body parts and placenta collected in polyethene bag and not transported outside from hospitals. The body fluids, chemical waste and wastewater from different wards are directly discharged into drainage of the metropolitan city and similar practices followed by entire hospitals of the metropolitan city in collection of solid and liquid biomedical waste.

In case of transportation, the biomedical waste collected manually by three staff everyday two times morning and evening in a day by the staff in separated dustbin and polyethene bags from each ward and transported to storage center by trolly.

Besides this, the hospital has their own biomedical waste management center is managing their waste inside the hospital and those has not management facility handover their biomedical waste to Green Hospital waste management center of metropolitan city. The collected waste in polyethene bags in different hospitals, storage their waste in back yards or separate storage place from there metropolitan vehicle collected waste manually and transported in semi-closed vehicle to Green Hospital waste management center.

Biomedical Waste Segregation Practices

The process of separating waste at the site of generation and keeping it apart for management, collection, temporary storage, and transportation is known as waste segregation. The most crucial stage in the effective management of biomedical waste is the segregation of waste at the point of generation, which is the fundamental principle of safe and effective waste reduction. During the study, 50 respondents were questioned and found that 74 percent responded to segregate biomedical waste in ward and remaining 26 percent segregated in management centre.

In the Narayani hospital biomedical waste such as Vials and Syringe segregated in the ward at same time of generation by medical staff and remaining such as saline bottle, cardboard box, plastic wrapper, intravenous set, cotton gauge and organic waste collected in dustbin without segregation. In the hospital, collected waste segregated in management center by staff manually everyday and kept in a separate storage shell. The remaining non-recyclable and organic waste items transferred in temporary disposal site to handover the metropolitan for final disposal.

The interviewed with 50 respondents (Patients and their associate, stakeholder, medical staff and workers) in various department for biomedical waste segregation practices in the hospital and 74% respondent (patients and their associated people) responded that do not have the idea regarding the segregation of biomedical and non-biomedical waste and through their organic and inorganic waste in mixing with biomedical waste. Only 26% respondent (medical staff and worker) were more conscious in segregation practices of biomedical waste. In the other hospitals of metropolitan, there is no any segregation practices and hospital waste along with organic, inorganic and biomedical waste directly handover to Green Hospital waste management center of metropolitan city.

Recycling of Biomedical Waste

The recycling means converting waste materials into new product by adding various process according to their nature. In the hospital various kinds of biomedical and inorganic waste generated that can be recycle such as plastic bags, slime bottle, gloves, water bottles, cardboards, intravenous set, cottons gauge, vials (glassware, glass tube and slides) and syringes after certain process. During the study, 0.05 tons/day, 0.36 tons/week, 1.56 tons/month and 18.74 tons/year of recyclable biomedical generated from the Narayani hospital represented in figure 13.

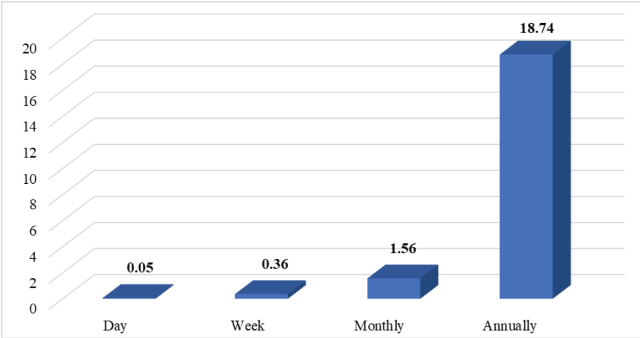

Figure 13: Generation of recyclable bio-medical waste from Narayani hospital in tons.

Similarly, from the entire hospital of the Birgunj Metropolitan city, 0.43 tons/day, 3.00 tons/week, 13.02 tons/month and 156.19 tons/year of recyclable biomedical waste generated. The figure 14 represented generation of recyclable bio-medical waste from entire hospital of Birgunj Metropolitan City in tons.

During the study, 38 percent of respondents responded to agree for recycling of waste. The liquid waste such as fluids, waste chemicals and wastewater had no any process of recycling and discharge directly in drainage. On the other hand, the removal of body parts and placenta used for production of bio-gas but in other hospital body parts and placenta dumped or buried in backyards.

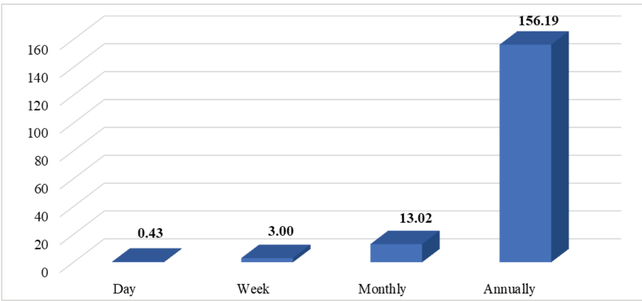

Figure 14 : The generation of recyclable bio-medical waste from entire hospital of Birgunj Metropolitan City in tons.

Disposal and Management of Biomedical Waste

The improper management of the biomedical waste is one of the biggest problems and arise various kind of human health, biodiversity and environmental issues in the hospital and metropolitan city. As the Green Hospital waste management center of metropolitan came in operation there is vast changes in the management and disposal of biomedical waste. Similarly, management center also provided its contribution in the management practices of organic and inorganic waste of Narayani hospital. However, the Narayani hospital has its own biomedical waste management center with modern technology-based auto-clave machine.

During the study, it was found that 0.05 tons/day and 0.43 tons/day volume of biomedical waste generated everyday in Narayani hospital and from other 35 hospitals of Birgunj Metropolitan City. The biomedical waste segregated and storage in shell and after auto-clave sell to vender from management center of Narayani hospital and similar, process is followed by metropolitan city for remaining hospital in Green Hospital waste management center.

The indoor and outdoor 50 responded were questioned regarding the disposal and management approach of biomedical medical waste and found that 88 percent respondents to collect waste in dustbin and 12 percent in Polyethene bags. Similarly, 12 percent respondents to incineration, 2 percent composting, 2 percent reuse, 38 percent recycle, 40 percent dumping and 6 percent do not know, advised to follow the biomedical waste management approaches.

The biomedical waste management inside the Narayani hospital and services provided by metropolitan city were inquired from 50 respondents responded that 42 percent good, 46 percent satisfactory and 12 percent poor management of biomedical waste experienced inside hospital and in metropolitan city. At the same time, only 8 percent of staff were involved in selling of recyclable waste outside to vender and 92 percent were not involved in such activities.

During the study entire hospital (35 hospital) of metropolitan city, handover the body parts and placenta to Green Hospital waste management center to dumped in landfill site. However, body parts and placenta are managed by production of bio-gas in Narayani hospital.

So far, the entire hospitals are managed their liquid waste such as body fluids, chemical along with wastewater directly discharge into drainage without any methods of treatment. From the study, among 50 respondent's 80 percent of medical, non-medical staffs, patients and their associate and other visitors did not show eco-friendly behavior and 20 percent have positive response in waste management system.

Biomedical waste may contain potential pathological organisms (Alagoz et al., 2008) which if improperly managed may be a risk to healthcare staffs, public and environment (Shine et al., 2008). During study, most of the respondents in 50, 48 percent of respondents were not but 52 percent were found environmental issues such as foul smell, soil pollution, spreading of waste by dogs and jackal and files problems. At the same time of study, 72 percent responded did not experienced any health issues and 28 percent were recorded as fever, cold, headache and diarrhea.

Conclusion and Recommendation

Conclusion

The study concluded that biomedical waste management system is satisfactory in Narayani hospital of Birgunj Metropolitan City. The segregation, collection, transportation, storage and disposal practice of the biomedical waste was found satisfactory. The mixing collection of organic, inorganic and medical waste were might be due to lack of proper training and instruction, carelessness of patients, visitors and staffs about waste segregation system.

The hospital administration, medical and non-medical staffs had also not given priority to effective waste disposal and management. Manual transportation of uncovered bucket and dustbin practiced by the sanitary staffs that may cause splitting of waste, foul smell, transmission and contamination of waste by vectors is hazardous to human health. Health care waste should be transported within the hospital and other facility by means of wheeled trolleys, containers or carts that are not used for any other purposes.

The biomedical waste such as vials, syringe, saline bottles, gloves, cardboard box, plastic wrapper, intravenous and cotton gauge found to be well segregated in Narayani hospital. Rather than, Narayani Hospital and other hospital of Birgunj Metropolitan City biomedical waste segregated in Green Hospital waste management center and finally sold to vender. The remaining waste were disposed in the absence of a special health care waste treatment facility. Therefore, hospitals should develop health care waste management plan strictly and training package for waste management should be developed for all hospital staffs including sweepers.

Recommendations

Strategy associated:

a. The Central Government as well as Local government should implemented policy of biomedical waste management and practices strictly the policy for the effective biomedical waste management in the hospital and other medical center.

b. The local government not only implemented the policy rather than established the local level waste management committee for the proper inspection and guidance for proper disposal and management of biomedical waste.

c. Besides the legal implementation, the financial and technical support should be also given by the government for the effective and efficient biomedical waste management system.

Improvement level:

a) The different color code dustbin should be placed inside and outside the wards, department and waiting places along with sign and symbol of types of waste for effective and efficient collection of segregated biomedical waste from every part of the hospital.

b) The hospital should conduct weekly or monthly or yearly awareness activities to their medical and non-medical staffs and also appointed a staff for guiding the local visitor for the proper collection of biomedical waste.

c) The hospital should follow the 3R (reduce, re-use & re-cycle) policy for the biomedical waste disposal and management.

d) The high rate of using plastic should be prohibited and instead of it the cotton or degradable bags should be encouraged to use.

e) The sanitary staff should wear the protective equipment for safe collection, handling, segregation and disposal of biomedical waste.

f) Nanostructured photo catalysts, due to their non-toxicity, low cost and high absorption efficiency can effectively degrade pollutants making them suitable for the treatment of biomedical waste management.

g) The educational program in campus and university is significantly enhance healthcare workers knowledge and practices regarding biomedical waste handling.

h) Innovative approaches are being explored to response biomedical waste materials such as plastic and glass into construction practices, promoting a circular economy and reducing environmental impacts.

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Nepal's Climate Diplomacy: Key Takeaways

Bharat Khanal
Government of Nepal
Correspondence: Bharatkhanal15@gmail.com

Abstract

This study explores the contours of Nepal's climate diplomacy mostly focusing on climate emergency, vulnerabilities and it's strategies, and role in global climate negotiations. Despite contributing minimally to global greenhouse gas emissions, Nepal ranks among the most climate-vulnerable nations. The research employs a multidisciplinary approach, combining quantitative content analysis with case studies, to provide actionable insights for Nepal. The research highlights Nepal's efforts to integrate climate action into national policies, advocate for climate justice, and leverage its geographical position to promote global action. By analyzing past climate negotiations, successful models from other countries, and Nepal's domestic policies, the study suggests a robust framework for enhancing its climate diplomacy. Key findings emphasize the importance of regional collaboration, science diplomacy, and equitable climate finance and improving domestic climate governance framework.

Keywords: *Climate change, climate diplomacy, climate justice, mountain agenda, negotiation, sustainable development*

Introduction

The climate emergency/crisis is a global concern and one of the greatest challenges of the 21st century. Climate issue is intense, complicated and delicate. Climate diplomacy merges climate and foreign policy by proactively linking national interest debates and international cooperation on climate change (Craft, 2014). Climate diplomacy refers to the use of diplomatic tools, negotiations, and international cooperation to address the global challenges posed by climate change. It involves fostering collaboration among nations, organizations, and stakeholders to mitigate greenhouse gas emissions, adapt to climate impacts, and ensure sustainable development (Council on Foreign Relations, 2013). Climate diplomacy operates at multiple levels, from bilateral and regional agreements to global frameworks like the Paris Agreement. The Paris Agreement in Cop 21, aims to limit the global temperature increase to 1.5 degrees Celsius above pre-industrial levels, building resilience and reducing vulnerability to climate impacts, and securing finance and support for low-carbon and climate-resilient development (The Kathmandu post, 2024). Climate diplomacy involves the understanding complex negotiation texts, climate science, and effective communication strategies.

Nepal's climate vulnerabilities emerge from a combination of fragile mountainous topography and ecosystems, highly variable monsoon-driven hydrology, unplanned settlements, and a lack of resilient infrastructure (MoEF, 2022). According to the Climate Risk Index, Nepal has ranked as the 10th most affected country in the world (Eckstein et al, 2021). Approximately 80 percent of its population is at risk from natural and climate-induced hazards, including extreme heat stress, flooding, and air pollution (GoN, 2018). Nepal's vulnerable communities, particularly in the mountainous regions, are at the mercy of glacial melt, flooding and landslides (The Himalayan, Feb 07, 2025).

This article discusses Nepal's current scenario of climate change and use of diplomacy to address the impacts of climate change. Highlighting the disproportionate impacts of climate change on Nepal it advocates for robust domestic institutions. It suggests the need of effective climate diplomacy to integrate climate actions into national development plans to address governance and financial challenges.

Methodology

This research is based on multidisciplinary approach with focus mixed methods. Focusing on empirical data, facts, descriptive and analytical study have been applied. Comparative cases and successful practices of other countries have been used. The study reflects both the primary and secondary data for analysis. Primary source is based on Government documents, foreign policy statements, foreign ministry reports and reports of international organizations dealing with climate change. Secondary sources include academic journals, books, magazines, theses, digital publications, websites, news reports, newspaper articles, and bulletins among others. The data collected from secondary sources have been explored, interpreted and analyzed. Media sources were also reviewed to understand various issues of Nepal's climate diplomacy.

Results

National policies on climate change

Article 51(g) of the Constitution on policies of the state mentions that "Policies relating to protection, promotion and use of natural resources: sustainable use of, natural resources available, adopting the concept of inter-generational equity, principles of environmentally sustainable development such as the principles of polluter pays, of precaution in environmental protection and of prior informed consent" (Constitution of Nepal, 2015). The major objective of National Climate Change Policy, 2019 is to address the adverse impacts of climate change, promote low-carbon development, and build climate-resilient communities. National Security Policy, 2016 identifies climate change as a threat to ecological equilibrium in Nepal. Climate adaptation, resilience, and green economic development are also key objectives of Nepal's 16th Periodic Plan (Rastriya Samachar Samiti, 2024). Other several sectoral policies also address the issue of climate change. New and integrated foreign policy of Nepal, 2020 unveils exchanging support for the study and research of science and diplomacy through science diplomacy.

Nepal's climate vulnerability and SDG alignment

SDGs, the right to development and climate change action as important aspects of the development diplomacy agenda for Nepal. Despite minimum contribution its highly affected. Nepal needs NPR 21.165 trillion from 2024 to 2030 to achieve the SDGs goals (NPC, 2025). This vulnerability directly affects its ability to achieve SDGs, particularly those related to poverty eradication (SDG 1), clean water and sanitation (SDG 6), and climate action (SDG 13). Nepal's climate actions must be closely aligned and integrated with its SDG targets. For example: renewable energy (SDG 7): Expanding hydropower and solar energy projects can reduce reliance on fossil fuels and promote sustainable energy access. Sustainable Agriculture (SDG 2), implementing climate-resilient agricultural practices can enhance food security and support rural livelihoods. Ecosystem Restoration (SDG 15): Reforestation and wetland conservation can mitigate climate impacts while preserving biodiversity. Climate diplomacy requires institutional reforms and more investment in resources and skills to navigate in the complex situation tossed by climate change (The Himalayan, 2021).

Mountain agenda in global climate diplomacy

The mountain agenda refers to the recognition and integration of mountain-specific issues within global climate negotiations and policy frameworks. Government of Nepal has been proactive in raising mountain issues and offering mountain solutions to the global communities in CoP process. Mountains are highly vulnerable to climate change, and their ecosystems play a critical role in global water resources, biodiversity, and cultural heritage. Despite their importance, mountains have often been underrepresented in international climate discussions. The Mountain Agenda seeks to address this gap by advocating for the inclusion of mountain-related concerns in climate policies, agreements, and actions. For the purpose, Nepal is coordinating with Global Mountain Partnership alliances and ICIMOD to take mountain agenda forward. Nepal's struggle against the impacts of climate change was discussed in the British Parliament, Alex Baker, a Member of Parliament representing the Labour Party, raised concerns about the issue in the House of Commons (The Kathmandu post, 2025). Nepal as "Water Tower of Asia," the Third Pole, which includes the Himalayan and Tibetan Plateau regions, holds the largest freshwater reserve outside of the polar regions and influences the hydrology of some of the world's most populous nations (Oli, K. P., & Pandey, M. R. (2024). Nepal can champion the inclusion of mountain-specific issues in global climate agreements, emphasizing the vulnerability of mountain ecosystems and communities. Changing geographies of rivers or glaciers may require diplomatic initiatives to balance interests and avoid disputes over borders or water rights (Carius et al., 2017).

Hindu Kush Himalayan Regional Cooperation

Nepal can lead or participate in regional initiatives with neighboring countries (e.g., India, China, Bhutan, and Bangladesh) to address transboundary climate challenges, such as water resource management and disaster risk reduction. Climate change always intersects with other key important sectors in this region, such as agriculture and food security, energy, trade, technical cooperation, and security (including cross-country migration because of climate change) (Pandey, 2022). Establishing a regional initiative could assist international climate diplomacy to raise the common agenda of South Asia in international forums. As seen in many South Asian countries, climate change has driven internal migration in Nepal, with communities in Himalayan, hilly, and Terai regions forced to relocate due to water scarcity, disrupted crop patterns, and extreme weather events. As climate impacts worsen, nations in the Third Pole, including Nepal and Bhutan, are using climate diplomacy to advocate for greater global recognition and support (Islam, 2022).

Climate finance and justice

Nepal as a staunch supporter of climate justice should emphasize the principle of "common but differentiated responsibilities" (CBDR) in international forums, highlighting that developed nations bear greater responsibility for climate change due to their historical emissions. Nepal can advocate for financial and technical support to address loss and damage caused by climate-induced disasters, such as glacial lake outburst floods (GLOFs) and landslides. Nepal should advocate for prioritizing climate action to access technology transfer, capacity building, and financial assistance. There is no doubt that mountainous regions are at the forefront of climate impacts: for example, high intensity rain and mountain slope instability can wash out roads and bridges (Big News Network, 2025), thereby affecting access to rural areas, and rapid change in mountain snow will have far reaching effects on both upstream and downstream (Nepali Times, 2021). Nepal would achieve the targets only if it received financial, technological, and capacity-building support from international actors, including global funds such as Green Climate Fund, Global Environment Facility (The Kathmandu post, 2022). Nepal's foreign minister led Nepali delegation to the International Court of Justice (ICJ) on December 2024 at the Court's public hearings on the 'Obligations of States in respect of Climate Change'. It was stressed that countries like Nepal are calling for is not mere handouts or charity, but compensatory climate justice (MOFA, 2024).

Nepal's journey from CoP 15 to CoP 29

Where climate change is concerned, the Copenhagen Summit of 2009 is a prime example. Table 1 below shows that representation has been at the highest level and due priority is given before participation like holding national climate conferences and so on from Nepal side. It also shows that representation has been at the head of the state, head of government minister for Environment and sometimes minister for science and technology and sometimes at the ambassadorial level.

At Cop 29 it was represented at the head of the state level in Baku with a side event dedicated on mountain agenda. In most of the interaction conferences and programs our participants are like climate tourist, only responsible members who can contribute should be the member of delegations in future COP.

Table 1: Brief outline of Nepal on high level delegation to UNFCCC

S.N.	COP	Level of Participation	Venue and Date
1.	COP15	Rt. Hon. Madhav Kumar Nepal, P.M.	Copenhagen, Denmark in 2009
2.	COP16	Hon. Minister for Environment Mr. Thakur Prasad Sharma	Cancun, Mexico in 2010
3.	COP17	Hon. Minister for Environment Mr. Hemraj Tater	Durban, South Africa in 2011
4.	COP18	Hon. Minister for MoSTE,Mr. Keshab Man Shakya,	Doha, Qatar in 2012
5.	COP19	H.E. Durga Pd. Bhattarai, PR to UN NY	Warsaw, Poland in 2013
6.	COP20	Rt. Hon. K P Sharma Oli, P.M.	Lima, Peru in 2014
7.	COP21	Hon. Minister for MoSTE, Mr. Vishwendra Paswan	Paris, France in 2015
8.	COP22	Hon. Minister for MoPE, Mr. Jay Dev Joshi	Marrakech, Morocco in 2016
9.	COP23	Hon. Minister for MoPE, Ms. Mithila Chaudhari	Bonn, Germany in 2017
10.	COP24	Rt. Hon. Bidya Devi Bhandari, President	Katowice, Poland in 2018
11.	COP25	Hon. Minister for MoEF, Mr. Shakti Bdr. Basnet	Madrid, Spain in 2019
12.	COP26	Rt. Hon. Sher Bahadur Deuba, P.M.	Glasgow, UK in 2021
13.	COP27	Rt. Hon. Sher Bahadur Deuba, P.M.	Sharmel-Sheikh, Egypt in 2022
14.	COP28	Rt.Hon. Pushpa Kamal Dahal, PM	Dubai, UAE in 2023
15.	COP 29	Rt. Hon. Ramchandra Paudel, President	Baku, Azerbaijan 2024

Table 2: Major govt. agencies of Nepal involved in climate diplomacy

S.N.	Key agencies	Divisions	Major tasks
1.	Office of the Prime Minister and Council of Ministers (OPMCM)	Cabinet Meeting and Constitutional Bodies Division	Policy guidance and coordination on climate change
2.	The Ministry of Forests and Environment (MoFE)	Climate Change Management Division	Serves as the national focal point
3.	Ministry of Finance (MoF)	International Economic Cooperation and Coordination Division	Funding and Financing climate change initiatives
4.	Ministry of Foreign Affairs (MoFA)	United Nation and Specialized Agencies Division	Coordinates Nepal's climate process at global level through its mission
5.	Ministry of Health and Population (MoHP)	Policy, Planning and Monitoring Division	Coordinates health impacts of climate change
6.	National Planning Commission (NPC)	Economic Development Thematic Group	Integrates climate change considerations into national development planning
7.	Ministry of Federal Affairs and General Administration (MoFAGA)	Policy and Development Assistance Coordination Division	Supports climate change policies at the local level
8.	Ministry of Agriculture and Livestock Development (MoALD)	Policy and Development Assistance Coordination Division	Oversees impacts of climate change on agriculture and livestock
9.	Ministry of Physical Infrastructure and Transport (MoPIT)	Development Assistance Coordination and Quality Division	Coordinates climate change impacts on disaster and infrastructure

Discussion

Although Nepal is grappling with the complexities of climate change its voice remains largely unheard in international climate forums. Managing climate change is a global problem, the solution of which mandates the unified efforts of the entire international community (Hristova, A., & Chankova, D. 2020). Climate change is science based but it is more of diplomatic and political agenda. Nepal's voluntary carbon markets, national commitments and regional climate projections offer opportunities for strategic climate diplomacy. Climate change is an appalling injustice and a searing indictment of the fossil fuel age for Nepal. Nepal needs to assume a leadership role in global climate platforms through a dedicated team of experts in its journey to transition to climate change (Pandey, C. L., & Dahal, N. 2022). Climate diplomacy, as an important component of economic diplomacy, needs to play a key role in receiving international assistance to deal with the climate crisis in Nepal (Malla, U. B. (2024).

Need for whole of the government approach in climate negotiations

Increasingly, countries are realizing that "whole of government" approach is needed to address climate change, and this approach must be reflected in the design and scope of climate diplomacy. Nepal needs robust legal system on climate change that requires mainstreaming climate issues in domestic documents before articulating national interest internationally. Whole of the government and concerted efforts are most in dealing with climate diplomacy. Nepal should segregate data based on scientific knowledge and disseminate with proper articulations. Nepal lacks research and development, good investment in it can produce good results. Tabel 2 shows that the issues of climate change is not the specific job of any government agency rather it is whole of the government approach.

Reinventing climate governance and climate authority at all levels

Nepal needs to strengthen institutional frameworks and need of dedicated high-level climate change authority with clear mandates, resources, and decision-making power to coordinate climate actions across ministries and agencies. That can enhance and improve collaboration between government departments, local governments, and stakeholders to ensure coherent policy implementation and avoid duplication of efforts. Nepal needs to decentralize climate actions from the federal agencies and integrate other governments and sectoral ministries. Functional coordination among all agencies is required. The Ministry of Finance needs coordination with the sectoral ministries regarding climate financing. MoFE is not alone to handle all the climate change related programs and needs to delegate the functions and resources to the sectoral ministries. The climate ambition must be translated into action by three tiers of government. Functions, functionaries, responsibilities and resources need to be devolved to the line ministries of federal, provincial and local governments to deliver effectively and efficiently.

As home is the first step of successful climate diplomacy, investing in training and capacity-building for negotiators and policymakers is crucial. The MoFE has made significant progress in developing climate change related national policies, strategies, and plans at the federal level, Inter-Ministerial Climate Change Coordination Committee (IMCCCC) and provincial level the Provincial Climate Change Coordination Committee (PCCCC) have been established and are operating to facilitate the functional coordination among government entities. Nepal needs a dedicated, high-level climate change authority with clear mandates, resources, and decision-making power to coordinate climate actions across ministries and agencies. Extreme weather events and climate-related disasters such as floods and landslides, have posed a significant threat to Nepal 's developmental ambitions (Government of Nepal, 2021). Climate change has also subsequently increased the risk of erratic monsoons as floods and landslides have become more frequent endangering and displacing entire communities (Government of Nepal, 2024).

Innovative initiatives on climate diplomacy

Small states should work to preserve and fully participate in a rules-based multilateral system that allows them to negotiate complex matters on an equal footing, regardless of size, population, strength or economic capacity. Bhutan has actively integrated legal expertise into its climate diplomacy efforts. Similarly, Denmark's Green Diplomacy (Copen Pay Initiative) has integrated climate action into its foreign policy, using its leadership in sustainability to enhance its global influence. Similarly, Green Frontline Missions of Denmark established 18 embassies focused solely on promoting climate diplomacy, emphasizing partnerships and financial support for developing countries. Ethiopian Panel on Climate Change plays an important role, generating evidence to support climate advocacy, and provides diplomats with a firmer foundation for influencing international negotiations.

Sagarmatha Sambaad

Government of Nepal successfully hosted Sagarmatha Sambaad in Kathmandu from 16 to 18 May 2025 under the theme of "Climate Change, Mountains and the Future of Humanity". Sagarmatha Sambaad is an appropriate platform for Nepal to pursue Nepal's just cause of Climate change. The rapid melting of snow and unpredictable precipitation have transformed once snow-clad glittering white mountains into black rocks.

(Sagarmatha Sambaad, 21 January 2025). The first edition of the Sagarmatha Sambaad concluded in Kathmandu with the adoption of the 25 action points 'Sagarmatha Call for Action'- a comprehensive and urgent appeal to the international community to address the escalating climate crisis, with an emphasis on the world's mountain ecosystems (The Kathmandu Post 2025).

Conclusion and way forward

Climate change is likely to continue in the future. Nepal should continue to advocate for transformative climate actions and secure adequate international funding, increase political capital, bolster national credibility, increase negotiators moral confidence. From Table 1, it can be concluded that Nepal had participated at the highest level in CoP process. But there lacks a national authority which is permanent in nature for overcall coordination. From Table 2, it can be said that climate change is no longer a technical issue, it's a political and geo-strategic issues involving various government departments. Nepal should Strengthen institutional coordination and capacity, mobilize additional climate finance from domestic and international sources, enhance community participation and ensure inclusivity in climate actions, leverage technology and innovation for effective implementation. Climate change and national security issues must be integrated. Nepal should carry out assessment, evaluation and monetary value in terms of compensation to take benefit from loss and damage fund. In the leadership of MoFA, an inclusive permanent type of inter disciplinary and multi-agency involved negotiation team must form for bilateral and multilateral climate CoP negotiation processes. Such team must include thematic ministries and outsider experts' team including research institutions, private sectors and universities. Nepal can be the best platform and neutral venue for regional climate initiation and share its experience with India and China.

Climate change, security and development issues should be closely worked out. Climate Negotiations team should include legal experts, data experts, climate researcher and geo strategic experts and should possess institutional memory. Climate diplomacy must be creative and proactive if it is to succeed. Make-shift attempts and quick fix solution are not always beneficial. There is an urgent need of climate research centre in our country. Today climate diplomacy is more of foreign and security policies. Further, Nepal should apply the concept of green economy in all economic sectors to strike a balance in the environment and adapt to climate change. With high moral ground Nepal should continue for urgent actions with evidenced based negotiations based on facts, figures and data and well documentation of past initiatives. Nepal's domestic policies should align with its diplomatic goals.

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