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Observing Effect by Accumulation of Particulate Matter on Plant Leaf Traits; Favorable for Controlling Atmospheric Pollution

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Abstract

Particulate matter (PM) accumulation on plant leaf surfaces is essential for reducing atmospheric pollution and simultaneously affecting plant physiological and morphological characteristics. This study examines the accumulation of coarse particulate matter (PM₁₁) on plant leaf surfaces and assesses its impact on selected leaf traits. A comparative field study was conducted at polluted and non-polluted sites in Barishal, Bangladesh, using leaves from nine plant species. The study quantified particulate matter deposited on leaf surfaces using a gravimetric method with a highly sensitive analytical balance (0.0001 g precision). Filtration was carried out using grade 1 filter paper with an 11 µm pore size. Leaf area was determined from scanned images analyzed with Image J software. Chlorophyll content was measured after acetone extraction using a UV–Vis spectrophotometer at wavelengths of 645, 663, and 652 nm. Additionally, the pH of leaf extracts was recorded using a digital pH meter. Five replicates were used for each species, and results were presented as mean ± standard deviation. Differences in PM₁₁ accumulation and leaf traits between polluted and non-polluted sites were analyzed using ANOVA, followed by Tukey's HSD test for pairwise comparisons. Pearson correlation was applied to assess relationships between PM₁₁ and leaf traits, with all analyses conducted at a significance level of $p < 0.05$. Leaf samples from specific plant species subjected to ambient particle pollution were gathered, and PM₁₁ deposition was measured using standardized washing and gravimetric techniques. Leaf traits, including specific leaf area (SLA), relative water content (RWC), leaf surface pH, chlorophyll and shape, were assessed to evaluate plant responses to PM₁₁ accumulation. A greater PM₁₁ accumulation has been linked to variation in leaf traits, including reduced SLA and chlorophyll concentration, suggesting limitations on photosynthetic efficiency.

Keywords: Particulate matter, Leaf traits, Polluted and non-polluted sites, Gravimetric method, UV–Vis spectrophotometer, Chlorophyll content and Relative water content.

Introduction

PM, or particulate matter, consists of heavy metals, black carbon, polycyclic aromatic hydrocarbons and other things that are floating around in the air. It is a significant source of air pollution in both developed and developing countries (Chen et al., 2015; Dzierzanowski et al., 2011; P. K. Rai, 2013). Human activity is the primary source of PM, which occurs in various sizes, shapes, origins, physical properties, and chemical compositions. (Kocić et al., 2014). Based on the aerodynamic diameter, PM can be divided into four groups: large ($>10\text{ }\mu\text{m}$), coarse ($2.5\text{--}10\text{ }\mu\text{m}$), fine ($0.1\text{--}2.5\text{ }\mu\text{m}$), and ultrafine ($\leq 0.1\text{ }\mu\text{m}$) (Dzierzanowski et al., 2011; Weber et al., 2014). Particle size is one factor that makes particulate matter harmful (Chaurasia & Karan, 2015). Large particles mostly settle in the respiratory system's gas-exchange areas during mouth-breathing. PM₁₁ consists of airborne particles with an aerodynamic diameter of $\leq 11\text{ }\mu\text{m}$, mostly belonging to the coarse fraction and commonly originating

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from dust, ash, pollen, and traffic-related emissions. Unlike PM_{10} ($\leq 10 \mu m$), PM_{11} includes a slightly wider size range, which makes it particularly relevant for evaluating particle deposition on leaf surfaces. Most previous studies on the particulate retention capacity of plants have predominantly focused on dust or PM_{10} . PM_{10} refers to inhalable particulate matter with an aerodynamic diameter of $10 \mu m$ or less, whereas PM_{11} includes particles up to $11 \mu m$, representing a slightly broader coarse particle fraction. Compared with PM_{10} , PM_{11} may include relatively larger coarse particles that have a greater tendency to settle on leaf surfaces, making them important for studies on foliar particulate accumulation. Coarse particles typically settle in the upper respiratory tract, whereas fine or ultrafine particles can reach the alveoli of the lungs (Bamniya, Kapoor, Kapoor, et al., 2012; Popek et al., 2013; P. K. Rai & Panda, 2014; Weber et al., 2014).

Plants are very important for reducing pollution in cities (Kapoor et al., 2013). Leaves and other plant components may serve as persistent accumulators of particulate matter (Liu et al., 2013). Studies show that the PM retention capacity of leaves is affected by their surface morphology, including filaments, cuticles, and epidermal structures (Bamniya, Kapoor, & Kapoor, 2012). Other factors that affect PM retention capacity include petiole length, phyllotaxy, tree height and canopy structure, plant age, leaf-surface wettability, and weather conditions (Liu et al., 2013; Popek et al., 2013; Sæbø et al., 2012; Wang et al., 2013). Urban trees substantially enhance air quality (Yang et al., 2005). For example, research conducted in Guangzhou, China, found that urban plants can retain 8,012.9 tons of dust annually (Liu et al., 2013). Speak et al. (2012) found that vegetation on a green roof could reduce PM_{10} emissions by 0.21 metric tons annually, approximately 2.3% ($\pm 0.1\%$) of those generated by a UK city. Yang et al. (2005) found that Beijing's trees removed 772 tons of PM_{10} from the air annually. Although plants can mitigate atmospheric particulate matter, specific studies of plant performance have shown that plant growth is affected by atmospheric pollution (A. Rai et al., 2010). The extent of this influence varies with plant species, pollutant characteristics and concentrations, and environmental factors (Chaturvedi et al., 2013; Wuytack et al., 2013). Particles that are accumulated on the surfaces of leaves have the potential to interfere with stomata and lower the amount of light that reaches the photosynthetic system (P. K. Rai, 2013; Terzaghi et al., 2013). Photosynthesis and growth would decline in both cases (Naidoo & Chirkoot, 2004). Pollution reduced petiole length and leaf area (Dineva, n.d.). Coal dust significantly decreased chlorophyll fluorescence and decreased carbon dioxide exchange on leaf surfaces by 17–39% (Naidoo & Chirkoot, 2004). In a contaminated environment, photosynthetic pigments, pH, and relative water content (RWC) significantly decreased, according to Kapoor et al. (2013), who studied the tree species *Dalbergia sissoo* Roxb. Chaturvedi et al. (2013) examined the impact of dust load (DL) on leaf characteristics, revealing significant reductions in SLA, RWC, and chlorophyll content at a polluted site. Previous studies have primarily examined how particulate matter affects leaf traits (Sharma & Tripathi, 2009) and accumulates on leaf surfaces. However, no study has looked at how PM_{11} particles affect the properties of the leaf.

Materials and Methods

Study sites and species selection

This study was conducted in Barisal, a divisional city in Bangladesh, located at $22.710^{\circ}N$, $90.363^{\circ}E$. The study was performed in two distinct environments: a heavily trafficked industrial area, designated as the polluted site, and the Ruler area, serving as the control site. The contaminated area includes Jalokhati Town, the South Alekanda Sogordi Bridge, Sonarga Textile Mills near the

Serniabad Bridge, Chowmatha Lake, and the Amtola Panir Tank. Coal particles and SO₂ are the primary air pollutants at the polluted site. Seven plant species, all of which are medium to large trees, were chosen based on field research at both sites. Detailed information about these species is presented in Table 1.

Table 1: Key characteristics of the plants identified at the two study areas.

Sample Locations	Plant species	Family	Habit
Sagordi bridge,	Mangifera Indica	Anacardiaceae	Medium tree
Rupatoli Bus stand	Artocarpusheterophyllus	Moraceae	Big tree
Sonargao textile mill	Ficus benghalensis (1)	Moraceae	Medium tree
Notullahbad Bus stand	Ficus benghalensis (3)	Moraceae	Medium tree
Chowmatha Bazar	Prunus dulcis	Anacardiaceae	Big tree
Zero point, Near Barisal university	Ficus benghalensis (3)	Rosaceae	Medium
Jalokathi Bus stand (Jalokathi)	Spondias mombian	Euphorbiaceae	Medium
Patuakhali chow Rasta (Patuakhali)	Ricinus communis	Moraceae	Big tree
Bakhergonj Bus stand (Barishal)	Dalbergia sissoo	Fabaceae	Medium

Instrumentation: All laboratory measurements were performed using properly calibrated instruments to ensure accuracy, reliability, and consistency of the results. The accumulation of particulate matter on leaf surfaces was quantified using a gravimetric approach, which provides a precise and reliable measurement of deposited particles. An analytical balance with a sensitivity of 0.0001 g was employed to ensure high accuracy in detecting even minute differences in mass. For the filtration process, Grade 1 filter paper with an 11 µm pore size was used, allowing effective separation and retention of particulate matter from the leaf wash. Leaf area, an important parameter for normalizing particulate deposition, was determined through digital image analysis. Leaves were scanned, and the images were processed using ImageJ (Version 1.40, developed by the National Institutes of Health, USA). This method ensures accurate and reproducible measurement of leaf surface area. To assess the physiological status of the leaves, chlorophyll content was estimated following extraction with acetone. The absorbance of the extract was measured using a UV–Visible spectrophotometer at wavelengths of 645 nm, 663 nm, and 652 nm, which correspond to the absorption peaks of different chlorophyll pigments. This multi-wavelength approach enables precise calculation of total chlorophyll content. Additionally, the pH of the leaf extract was measured using a digital pH meter to evaluate the acidity or alkalinity of the leaf tissues. This parameter provides insight into biochemical changes in the leaves, which may be influenced by environmental factors such as particulate pollution. Overall, the methodology integrates physical, morphological, and biochemical measurements to comprehensively evaluate particulate matter deposition and its potential effects on plant health.

Statistical analysis: Five independent replicates were analyzed for each plant species to ensure statistical robustness and minimize experimental variability. The collected data were summarized and presented as mean values accompanied by their corresponding standard deviations (mean ± SD), providing a clear representation of central tendency as well as the dispersion within each dataset. To

examine differences in PM₁₁ accumulation and associated leaf traits between polluted and non-polluted sites, an analysis of variance (ANOVA) was applied. This statistical test enabled the assessment of whether observed variations among groups were statistically significant. Following ANOVA, Tukey's Honestly Significant Difference (HSD) test was conducted as a post hoc analysis to perform pairwise comparisons and identify specific group means that differed significantly from one another. In addition, Pearson correlation analysis was carried out to explore the strength and direction of relationships between PM₁₁ accumulation and various leaf characteristics. This helped in understanding how particulate deposition is associated with physiological and morphological traits of the leaves. All statistical analyses were performed at a significance level of $p < 0.05$, indicating that differences and relationships were considered statistically significant when the probability of occurrence by chance was less than 5%.

Acquisition of samples

The plants examined were in excellent condition and had few or no pests or diseases. The analysis did not include any leaves that had bugs or parasites on them. Five individuals (copies) of similar size were used to take leaves from each species. For each tree, healthy, mature leaves were collected from the east, south, west, and north sides at heights of 0.5 to 3 m above ground, depending on the height of the trees (Liu et al., 2012). To get enough material for PM₁₁ measurements and to keep particles from getting stuck during filtration, the leaf area per species had to be between 300 and 400 cm². The control site needed a bigger leaf area. (Dzierzanowski et al., 2011). All samples were gathered in August 2022, after the growing season. Two weeks following a period of heavy rainfall, as described by Wang and Li (2006), the sampling was conducted. In order to ensure consistency in temperature and humidity conditions, all samples were collected on the same day, sealed in polyethylene bags, and kept in the laboratory until analysis. The samples were kept in an icebox while they were being taken to the lab.

Detailed quantitative analysis of particulate matter

The PM on the leaf surface was measured gravimetrically (Dzierzanowski et al., 2011). The filter membranes were first and later weighed using an electronic balance that could detect changes as small as 0.0001 g. Grade 1 filter paper having pores that are 11 μm wide was used for filtration (Dzierzanowski et al., 2011). After scanning, Image J software (Version 1.40, National Institutes of Health, USA) was used to measure the leaf area of the washed samples (Wang et al., 2013). Because PM came from both the top and bottom of the leaves, the amount that accumulated for each species was represented per unit area of leaf surface and estimated using the following equation:

$$W = (W_2 - W_1) / 2A$$

W is the total amount of PM ($\mu g \text{ cm}^{-2}$) on the leaf, W_1 is the weight of the filter paper before the PM was added (μg), W_2 is the weight of the filter paper after the PM was added (μg), and A is the area of the sample leaves that were scanned (cm²).

Analysis of leaf traits

SLA appears to be the area per unit dry mass of leaf, measured under the assumption of Chaturvedi et al. (2013). However, in this study, the leaf was washed before oven-drying to minimize the effects of surface particles. RWC was assigned as a percentage of (leaf fresh mass - leaf dry mass) / (leaf

saturated fresh mass - leaf dry mass), following the methodology outlined by Sen and Bhandari (1978). The concentrations of chlorophylls (Chl a and Chl b) and carotenoids in fresh leaf samples collected from a polluted area and a control site were analyzed using colorimetric methods at wavelengths of 645 nm, 663 nm, and 652 nm with an ultraviolet spectrophotometer following extraction in acetone. The pH of the leaf extract was measured using the technique developed by Prasad and Rao (1982). One gram of the leaf sample was mixed with 10 mL of deionized water. The homogenate was centrifuged, and the resulting supernatant was collected and analyzed using a digital pH meter.

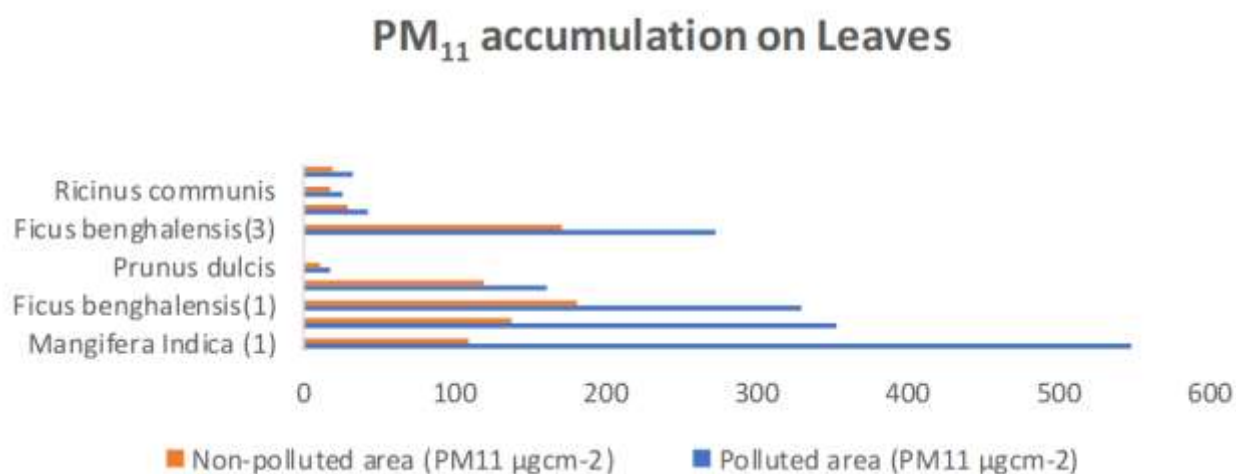
Results

PM accumulation of plant species

The study demonstrates that PM₁₁ accumulation on leaf surfaces differs markedly among plant species and across sampling locations, reflecting both environmental conditions and species-specific leaf traits. In polluted areas, *Mangifera indica* showed the highest accumulation (549.32 μgcm^{-2}), followed by *Artocarpus heterophyllus* (354.83 μgcm^{-2}) and *Ficus benghalensis* (329.95 μgcm^{-2}), indicating that these species are particularly efficient at capturing airborne particles. This high retention capacity is likely due to morphological and physiological features such as rough or hairy leaf surfaces, thicker cuticles, waxy coatings, and larger leaf areas, all of which enhance particle adhesion and reduce resuspension. In contrast, *Prunus dulcis* exhibited the lowest PM₁₁ accumulation (17.83 $\mu\text{g cm}^{-2}$), suggesting a limited ability to trap particulates, possibly due to smoother leaf surfaces, lower surface complexity, or reduced wax content. The observed variation highlights that plant species differ significantly in their role as natural biofilters, with some species being far more effective in mitigating particulate pollution. Consequently, species like *Mangifera indica*, *Artocarpus heterophyllus*, and *Ficus benghalensis* are better suited for plantation in pollution-prone areas to improve air quality, whereas *Prunus dulcis* may contribute less to particulate removal. In unpolluted areas, PM₁₁ levels were much lower across all species, ranging from 11.10 to 182.72 $\mu\text{g cm}^{-2}$. *Ficus benghalensis* had the most PM₁₁ load at non-polluted sites (182.72 $\mu\text{g cm}^{-2}$), while *Prunus dulcis* had the least (11.10 $\mu\text{g cm}^{-2}$). In general, PM₁₁ levels were consistently higher in polluted areas than in clean places. This shows that human activities in the area had an effect. The percentage decrease in PM₁₁ between polluted and unpolluted areas ranged from 25.87% to 63.64%. *Mangifera indica* had the best reduction efficiency (63.64%), followed by *Artocarpus heterophyllus* (60.87%). This suggests that these plants are better at capturing and retaining airborne particles. There was a moderate drop in PM₁₁ levels in *Dalbergia sissoo* (39.72%), *Prunus dulcis* (37.77%), and *Spondias mombin* (31.14%). The *Ficus benghalensis* at the Barishal University site had the lowest reduction percentage (25.87%). These results show that different plants vary in their ability to retain PM₁₁, and they also suggest that some tree species could help reduce particulate pollution in cities.

Table 2 : PM₁₁ accumulation on plant leaf surfaces across study sites.

Plant species	Polluted area (PM ₁₁ µgcm ⁻²)	Non-polluted area (PM ₁₁ µgcm ⁻²)	Percentage of PM ₁₁ reduction (%)	Sample Locations
Mangifera Indica (1)	549.324	109.720	63.64	Sagordi bridge
Artocarpus heterophyllus	354.83	138.82	60.87	Rupatoli Bus Stand
Ficus benghalensis (1)	329.949	182.724	44.62	Sonargaon textile mill
Ficus benghalensis (2)	162.345	120.342	25.87	Zero point, Near Barisal University
Prunus dulcis	17.832	11.096	37.77	Chowmatha Bazar
Ficus benghalensis (3)	274.450	172.65	37.09	Notullahbad BusStand
Spondias mombian	42.456	29.233	31.14	Jalokathi Bus stand (Jalokathi)
Ricinus communis	27.254	18.412	32.44	Patuakhali chow rasta (Patuakhali)
Dalbergia sissoo	32.45	19.56	39.72	Bakhergonj Bus stand (Barisal)

**Fig.1: Illustrates the accumulation of PM₁₁ (particulate matter ≤11 µm) on the leaf surfaces of different plant species across polluted and non-polluted study sites**

The fig.1 clearly shows that PM₁₁ deposition is substantially higher in polluted areas compared to non-polluted ones for all species, indicating a strong influence of anthropogenic activities on particulate load. Among the studied plants, *Mangifera indica* exhibits the highest PM₁₁ accumulation at polluted sites, followed by *Artocarpus heterophyllus* and *Ficus benghalensis*, suggesting their greater tendency to capture and retain airborne particles. In contrast, *Prunus dulcis* consistently records the lowest PM₁₁ accumulation, reflecting its comparatively lower particle retention efficiency.

At non-polluted sites, PM₁₁ levels are significantly reduced across all species, though *Ficus benghalensis* still shows relatively higher accumulation than others, while *Prunus dulcis* remains the lowest. The variation between polluted and non-polluted conditions is further emphasized by differing reduction percentages among species, with *Mangifera indica* and *Artocarpus heterophyllus* showing the most pronounced decreases, indicating higher efficiency in particulate capture.

Overall, the fig.1 highlights both the impact of environmental pollution on particulate deposition and the species-specific differences in the ability of plants to trap airborne particles, suggesting their potential role in urban air pollution mitigation.

Leaf traits

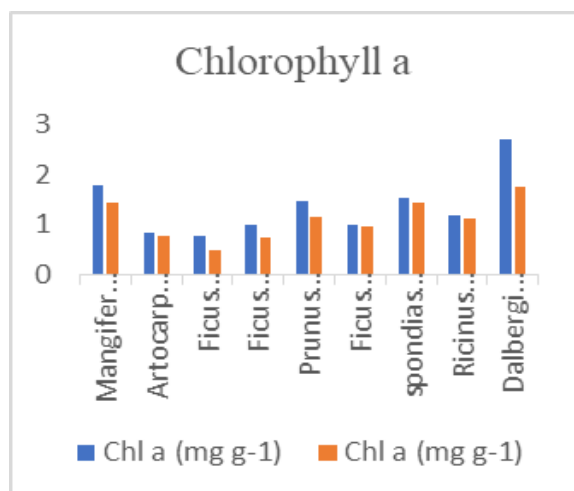
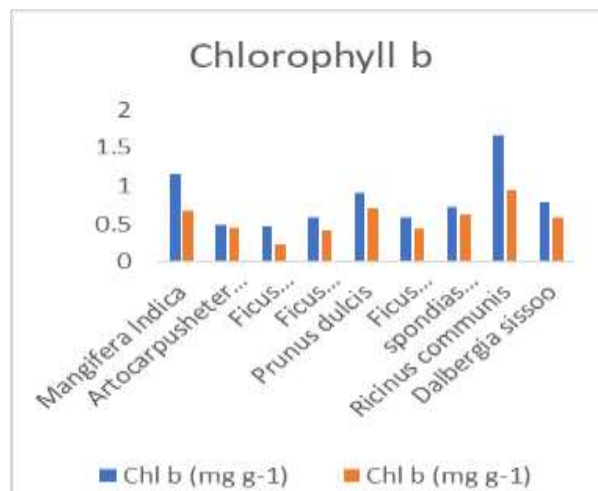
The analysis of leaf characteristics revealed distinct differences between the non-polluted area (NPA) and the polluted area (PA) across the examined plant species (Table 3).

In general, chlorophyll pigments, pH, SLA, and relative water content (RWC) decreased when PA was present compared with NPA. However, the magnitude of the response varied across species. The findings demonstrate a uniform reduction in the physiological and biochemical characteristics across all examined plant species under polluted-area (PA) conditions relative to non-polluted areas (NPA). The levels of chlorophyll a, chlorophyll b, and total chlorophyll were generally higher in NPA. This suggests that airborne pollutants adversely affect the synthesis and stability of photosynthetic pigments. Leaf pH values showed a noticeable reduction in PA for most species, indicating that leaf surfaces became more acidic upon pollutant absorption. Specific leaf area (SLA) decreased significantly at polluted sites, suggesting that thicker or denser leaves are an adaptive response to environmental stress. The observed decreases in chlorophyll content, pH, SLA, and RWC under PA indicate that air pollution substantially modifies leaf functional traits and physiological performance (Beckett et al., n.d.; Paolettia et al., 2011; Prusty et al., 2005).

This fig.2 shows that chlorophyll-a concentration is generally higher in leaves from non-polluted sites compared to polluted ones. The decline in chlorophyll-a under polluted conditions suggests that air pollutants, particularly particulate matter, may negatively affect photosynthetic pigments. Since chlorophyll-a is the primary pigment involved in photosynthesis, its reduction indicates possible impairment of photosynthetic efficiency. The extent of decrease varies among species, reflecting differences in their tolerance to pollution stress. Similarly, Fig.3 demonstrates that chlorophyll-b levels are also reduced in polluted environments. Chlorophyll-b acts as an accessory pigment, supporting light absorption and transferring energy to chlorophyll-a. The observed decrease implies that pollution not only affects primary pigments but also disrupts the overall photosynthetic system. As with chlorophyll-a, the degree of reduction differs among species, indicating species-specific sensitivity or adaptability. Together, these figures highlight that air pollution has a detrimental effect on leaf chlorophyll content. Plants growing in cleaner environments maintain higher pigment concentrations, while those in polluted areas experience pigment degradation. This reduction in chlorophyll-a and chlorophyll-b suggests stress-induced damage to the photosynthetic machinery, which may ultimately affect plant growth and productivity.

Table 3 : Average leaf trait parameter values of 9 plant species at the two different sites.

Plant species	Chl a (mg g ⁻¹)		Chl b (mg g ⁻¹)		Total chlorophyll (mg g ⁻¹)		pH		SLA(cm ² g ⁻¹)		RWC(%)	
	NPA	PA	NPA	PA	NPA	PA	NPA	PA	NPA	PA	NPA	PA
Mangifera Indica	1.780	1.430	1.152	0.668	0.0034	0.0029	7.76	7.33	0.489	0.479	98.32	96.24
Artocarpusheterophyllus	0.837	0.778	0.483	0.455	0.0016	0.0015	8.11	7.92	0.437	0.409	80.94	80.39
Ficus benghalensis (1)	0.759	0.492	0.459	0.233	0.0014	0.0012	7.97	7.74	0.314	0.119	84.13	83.95
Ficus benghalensis (2)	0.977	0.741	0.576	0.411	0.0019	0.0016	9.91	9.11	5.357	3.514	79.66	79.53
Prunus dulcis	1.460	1.151	0.902	0.698	0.0028	0.0022	6.56	5.51	5.098	3.086	96.37	74.18
Ficus benghalensis (3)	0.977	0.962	0.576	0.440	0.0019	0.0017	9.91	9.04	5.357	3.724	88.83	86.59
spondias mombian	1.540	1.416	0.714	0.624	0.0027	0.0023	8.45	8.12	0.863	0.534	92.63	90.15
Ricinus communis	1.168	1.102	1.662	0.944	0.0029	0.0018	9.22	9.95	1.976	1.634	83.07	82.83
Dalbergia sissoo	2.71	1.74	0.79	0.59	0.0044	0.0025	7.49	6.98	1.890	1.567	52.15	52.05

**Fig.2: Chlorophyll-a concentration of sample leaves across non-polluted and polluted sites.****Fig.3: Chlorophyll-b concentration of sample leaves across non-polluted and polluted sites.**

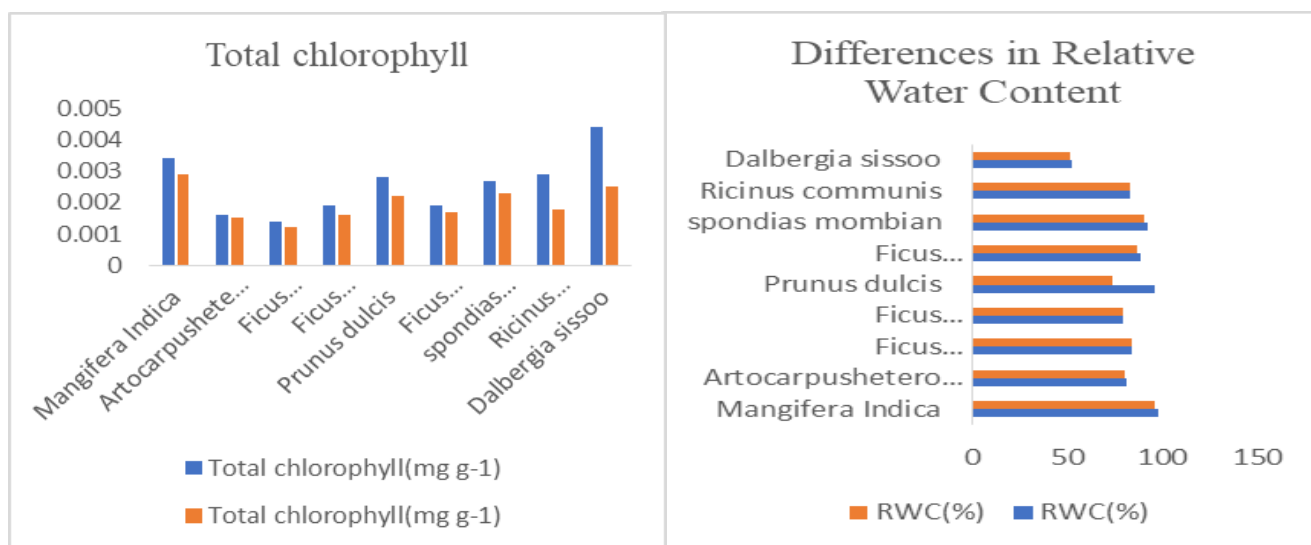


Fig.4: Total Chlorophyll concentration of sample leaves across non-polluted and polluted sites.

Fig.5: Relative water content (RWC) of leaves at polluted and non-polluted study sites.

This fig.4 shows the combined concentration of chlorophyll-a and chlorophyll-b in leaf samples. In general, total chlorophyll content is higher in plants from non-polluted sites and reduced in those from polluted areas. This decline indicates that air pollution, particularly particulate matter deposition, may lead to degradation of photosynthetic pigments or inhibit their synthesis. As total chlorophyll is directly linked to photosynthetic capacity, its reduction suggests that plants in polluted environments may experience decreased photosynthetic efficiency and overall physiological stress. The extent of reduction varies among species, reflecting differences in their tolerance and adaptive mechanisms to pollution. This fig.5 represents the water status of plant leaves, which is an important indicator of plant health and hydration. Leaves from non-polluted sites generally exhibit higher RWC values, indicating better hydration and physiological stability.

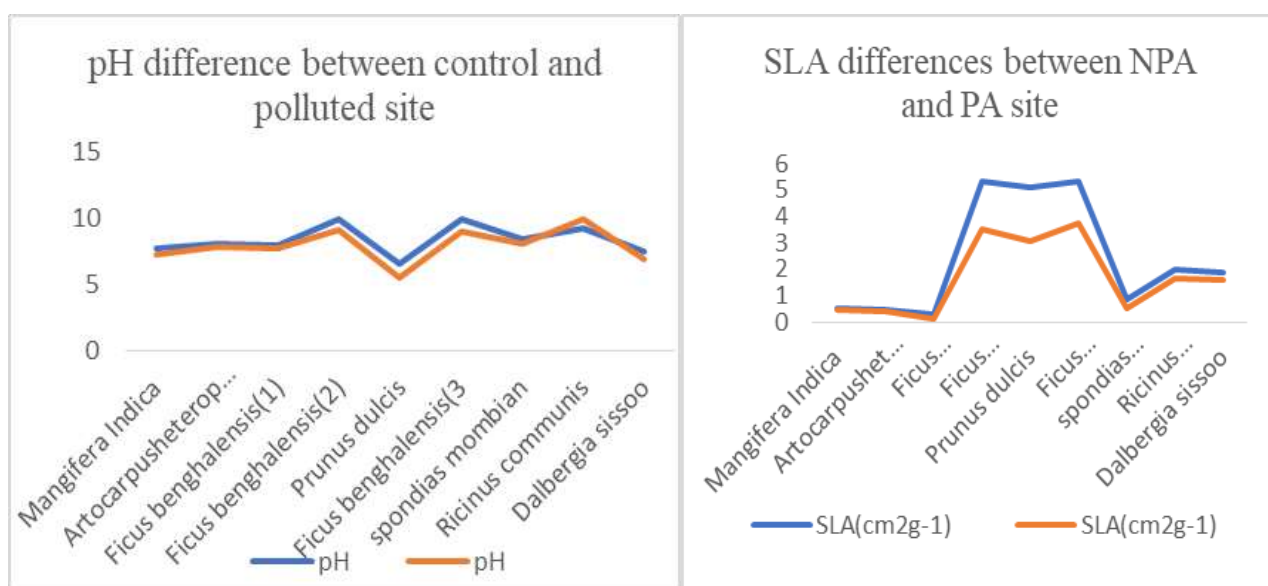


Fig. 6: pH difference of leaves between non poluted and polluted site

Fig.7: SLA differences between NPA and PA site.

In contrast, plants from polluted sites tend to show reduced RWC, suggesting that pollution stress may impair water retention ability, possibly due to damage to leaf structure or altered stomatal function. Lower RWC reflects reduced turgidity and may affect metabolic activities, including photosynthesis and nutrient transport.

Overall Interpretation these figures demonstrate that polluted environments negatively impact both the photosynthetic pigment content and water balance of plants. Reduced total chlorophyll and RWC in polluted sites indicate physiological stress, while higher values in non-polluted areas reflect healthier plant conditions. These parameters collectively highlight the sensitivity of plant systems to environmental pollution and their usefulness as bioindicators of air quality.

Fig.6 and Fig.7 highlight important biochemical and morphological changes in plant leaves under polluted and non-polluted conditions.

Fig.6 (Leaf Extract pH) shows the variation in pH of leaf extracts between non-polluted and polluted sites. Generally, leaves from polluted areas tend to exhibit lower pH (more acidic) compared to those from non-polluted sites. This decrease in pH may be attributed to the accumulation of acidic pollutants (such as sulfur and nitrogen oxides) and particulate matter on leaf surfaces, which can alter the internal biochemical environment. A lower leaf pH indicates stress conditions and may affect enzymatic activities, metabolic processes, and overall plant health. In contrast, higher or near-neutral pH values in non-polluted sites reflect a more stable and healthy physiological state. Fig.7 represents the differences in Specific Leaf Area (SLA) between non-polluted areas (NPA) and polluted areas (PA). SLA is the ratio of leaf area to dry mass and is an important indicator of leaf structure and adaptation strategies. Typically, plants in polluted environments may show altered SLA values—either increased or decreased depending on species response. A lower SLA often indicates thicker, denser leaves, which may be an adaptive response to pollution stress, helping to reduce pollutant penetration and water loss. Conversely, higher SLA suggests thinner leaves, which may be more sensitive to environmental stress.

Overall these figures suggest that pollution not only affects internal biochemical properties (like pH) but also influences leaf structural characteristics (such as SLA). Changes in these parameters reflect plant stress responses and adaptive mechanisms, making them useful indicators for assessing the impact of environmental pollution on vegetation.

Discussion

Our findings show that the particulate matter (PM) retention capacity of plant leaves varies significantly across locations and plant species. Environmental factors and species-specific leaf characteristics play a vital role in determining the degree of PM accumulation on leaf surfaces. The retained PM adversely affects leaf traits, including morphological and physiological factors (Joshi & Bora, n.d.). PM₁₁ accumulates on leaf surfaces through dry deposition, impaction, and interception, and its retention is enhanced by leaf roughness, wax layers, trichomes, and stomatal openings. In polluted areas, excessive PM₁₁ deposition forms a surface layer that reduces light penetration and may block stomata, thereby limiting gas exchange and transpiration. This stress can suppress chlorophyll synthesis, reduce relative water content, alter leaf surface pH, and decrease specific leaf area (SLA), indicating structural and physiological adaptation to particulate pollution. Overall, PM accumulation on leaf surfaces has considerable adverse effects on all examined leaf traits.

Difference in PM₁₁ accumulation by locations and species

The findings revealed distinctions in PM₁₁ accumulation between the 2 sites and among the 9 plants, thereby validating our first prediction. PM accumulation data showed that there was more PM on the surfaces of leaves at polluted places. This was probably because there was more air pollution from burning coal and heavy traffic (average particle concentration $198.9877 \mu\text{g cm}^{-2}$). On the other hand, the control site had high forest cover and relatively low traffic volume (particulate concentration $89.173 \mu\text{g cm}^{-2}$). PM accumulation data demonstrated elevated PM deposition on leaf surfaces at contaminated sites, likely attributable to increased air pollution resulting from coal combustion and heavy traffic (average particulate concentration $198.9877 \mu\text{g cm}^{-2}$). Pollutant deposition depends on deposition velocity and pollutant concentration (Tallis et al., 2011). Chaturvedi et al. (2013) reported that dust load on the tree species was present at the most polluted site. According to Saebø et al. (2012), PM accumulation on plant leaves varies by species and pollution levels. Differences in PM retention among plant species in the same area were also significant.

Among the studied species, *Mangifera indica* had the highest PM₁₁ load under polluted conditions ($549.324 \mu\text{g cm}^{-2}$) with a significant 63.64% decline in the non-polluted area, implying its high efficiency in retaining coarse particulates. Likewise, *Artocarpus heterophyllus* exhibited a substantial reduction in PM₁₁ (60.87%), indicating strong dust interception capability. *Ficus benghalensis*, on the other hand, showed variable PM₁₁ retention across different locations, with percentage reductions ranging from 25.87% to 44.62%, reflecting the combined effects of site conditions and micro-environmental exposure. Reduced PM₁₁ accumulation was identified in species such as *Prunus dulcis*, *Ricinus communis*, and *Spondias mombin*, which retained relatively lower particulate loads, possibly due to smoother leaf surfaces or reduced leaf area available for particle deposition. These findings align with previous studies indicating significant variation in particulate retention among species (Bamniya, Kapoor, Kapoor, et al., 2012; Kapoor et al., 2009; White & Montes-R., 2005). Overall, the connection between plant species and sampling location significantly influenced PM₁₁ accumulation, underscoring the need for species-specific selection in urban areas. Species such as *Mangifera indica* and *Artocarpus heterophyllus* are particularly effective for roadside and high-traffic areas due to their higher PM₁₁ retention capacity.

Impact of particulate matter on leaf characteristics

The current studies reveal apparent differences in chlorophyll content, leaf pH, specific leaf area (SLA), and relative water content (RWC) between plants growing in non-polluted areas (NPA) and polluted areas (PA), highlighting the influence of particulate stress on plant physiological performance. Across all investigated species, chlorophyll a, chlorophyll b, and total chlorophyll contents were generally higher in non-polluted areas than in polluted areas. This decrease under polluted conditions indicates degradation of photosynthesis, likely due to particulate deposition on leaf surfaces, which may restrict light permeability and affect chloroplast function. For most species, Leaf extract pH exhibits a general decrease in PA compared to NPA. Specific leaf area (SLA) declined under polluted atmospheric conditions across all species, indicating thicker or denser leaves under contaminated conditions. Notably, *Ficus benghalensis* and *Prunus dulcis* showed reductions in SLA, indicating a consistent morphological response to pollution stress. Similarly, relative water content (RWC) was generally lower in the polluted area, reflecting declined water-holding capacity and stomatal dysfunction due to particulate blockage.

Conclusion

This study focused on PM₁₁ accumulation on leaf traits of 9 plant species and assessed the impact on various leaf traits. The results indicated that PM₁₁ accumulation markedly affected the morphological and physiological characteristics of the leaves, including specific leaf area, chlorophyll content, relative water content and pH. A clear interaction was observed between PM₁₁ accumulation and leaf traits such as SLA, chlorophyll content, leaf pH and relative water content, emphasizing the importance of leaf structure in retaining particulate matter. Our findings indicate that plants with higher PM₁₁ retention capacity may play a crucial role in controlling air pollution and maintaining environmental quality in good condition (Kapoor et al., 2012; Kocić et al., 2014). Future studies should examine how PM accumulation affects plant health over time to improve the use of plants for pollution control. Further studies are needed to clarify the mechanistic pathways by which PM₁₁ deposition alters leaf morphology and physiology in polluted environments.

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Adsorptive Removal of Cr(VI) from Aqueous Solution Using Shrimp Shell-Based Adsorbent: Isotherm and Kinetic Studies

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Abstract: This study investigates the efficacy of shrimp shell as a bio-adsorbent for the reduction of Cr(VI) from aqueous systems, highlighting its adsorption capacity, isothermal compatibility, and kinetic characteristics. Under optimized conditions, a maximum adsorption efficiency of 47.22% was achieved at an initial Cr(VI) concentration of 5 ppm, 2 g of adsorbent, at a pH of 6.78, 25 °C, and 60 min of contact time. The adsorption behavior exhibited superior alignment with the Freundlich isotherm, suggesting multilayer adsorption on heterogeneous surfaces, compared to the Langmuir isotherm. Kinetic modeling revealed that the adsorption process is better represented by the pseudo-second-order mode than the pseudo-first-order model, indicating chemisorption as the predominant mechanism. Further, the Fourier transformed infrared (FTIR) spectroscopy analysis of shrimp shells before and after Cr(VI) adsorption showed notable shifts in functional groups, confirming the binding interactions of Cr(VI) ions with the active sites on the shrimp shell surface. The findings of this research highlight the potential of shrimp shell as an affordable, sustainable material to remove heavy metals (Cr(VI)) from wastewater.

Keywords: Shrimp shell, Cr(VI) removal, Adsorption, Freundlich isotherm, Pseudo-second-order kinetics, Infrared spectroscopy, Eco-friendly adsorbent, Sustainable water treatment.

Introduction

Water is one of the most essential resources, crucial for the existence of all living species, including humans, as well as for food production and economic development (Halder and Islam 2015). However, with the rise of industrial activities and the expansion of urban areas, water pollution has become an increasingly critical issue worldwide. Contaminants from domestic, agricultural, and industrial sources frequently enter rivers, lakes, and groundwater, compromising water quality and posing serious health risks to humans and animals (Singh and Gupta 2017; Bej et al., 2023). Among various pollutants, heavy metals are especially concerning due to their persistence in the environment, bioaccumulation in living organisms, and toxicity even at low concentrations (Kanwar et al., 2020; Soliman and Moustafa 2020).

Hexavalent chromium (Cr(VI)) is a commonly found heavy metal that is toxic and frequently detected in industrial wastewater (Nur-E-Alam et al., 2020; Prasad et al., 2021). It is extensively used in pigment production, electroplating, steel manufacturing process, as well as in leather tanning (Rosales-Landeros et al., 2013; Khatun et al., 2023). Cr(VI) pollution in Bangladesh is predominantly attributed to anthropogenic activities, especially industrial operations. Among these, tannery industries represent the most significant source, as large amounts of chromium salts used in leather processing are discharged into surrounding water bodies without adequate treatment. In addition, effluents from electroplating, textile dyeing, and various chemical industries contribute substantially to chromium contamination in aquatic and terrestrial environments (Karim et al., 2013; Zeng et al., 2025). Metallurgical processes and the combustion of fossil fuels also release chromium into the atmosphere, which subsequently deposits onto soil and water surfaces. Furthermore, improper disposal of industrial sludge and solid waste facilitates the accumulation of chromium in soil and groundwater systems. Collectively, these sources elevate chromium concentrations locally, posing

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serious risks to environmental and human health (Das et al., 2025). Because of its high solubility in water and strong oxidative properties, Cr(VI) is extremely mobile in aquatic environments as well as is able to penetrate biological membranes (Mondal et al., 2018; Ukhurebor et al., 2021). Chromium contamination can harm aquatic organisms by destroying gill tissues, slowing growth, impeding reproduction, and causing oxidative stress (Khatun et al., 2024). In plants, Cr(VI) disrupts photosynthesis, inhibits seed germination, and alters nutrient uptake, causing stunted growth (Shanker et al., 2005). In humans, exposure of Cr(VI) is associated to numerous detrimental health effects, including skin irritation, respiratory problems, organ damage, and an elevated risk of cancer (Chand et al., 2009; Enniya et al., 2018; Xie 2024). For example, skin contact frequently causes allergic reactions, dermatitis, and ulcers. Furthermore, long-term exposure, even at low concentrations, may result in chronic health issues, making Cr(VI) a critical pollutant of concern (Sharma et al., 2022). Due to these dangers, internationally recognized regulatory bodies have set strict limits on Cr(VI) levels in drinking water (Joseph et al., 2019).

Cr(VI) can be eliminated from wastewater using a variety of treatment methods, such as coagulation–flocculation, ion-exchange, membrane filtration, and electrochemical techniques (Atikah et al., 2023). While effective under certain conditions, these technologies often involve high operational costs, complex equipment, and potential generation of hazardous byproducts. These limitations have led researchers to explore more sustainable, affordable, and efficient alternatives for water purification (Ramli et al., 2023; Selvi et al., 2001).

Adsorption has emerged as a preferred method to eliminate heavy metals such as Cr(VI) from water because of its ease of use, cost-effectiveness, along with its capacity to function at low contaminant concentrations (Alaqarbeh et al., 2021; Sume et al., 2024; Miah et al., 2022). The achievement of this method largely depends on the choice of adsorbent material. Recently, interest has grown in using low-cost, natural, and biodegradable substances, especially those derived from agricultural and marine waste, as eco-friendly adsorbents (Rathi and Kumar 2021; Wen et al., 2011).

Shrimp shell waste is one such promising material. Commonly discarded by seafood processing industries, shrimp shells are a significant environmental burden in coastal regions (Rahman et al., 2023). However, their composition-rich in chitin, proteins, and calcium carbonate-offers a range of functional groups, such as hydroxyl (-OH), amino (-NH₂), and carboxyl (-COOH), that can efficiently attach to some heavy metal ions (Hisham et al., 2021). Utilizing shrimp shells as a biosorbent not only reduces waste but also provides a renewable as well as sustainable solution for water treatment (S et al., 2016; Dima et al., 2015; Ibrahim and Qader 2024).

Previous studies have shown that shrimp shells can be used as a low-cost and environmentally friendly adsorbent for removing pollutants, particularly heavy metals, from water. This is mainly due to the presence of chitin, proteins, and calcium carbonate, which provide functional groups that help in binding metal ions. Both raw and treated shrimp shells have been reported to effectively remove contaminants such as Cr(VI), Pb(II), and Cd(II), indicating their potential use in wastewater treatment (Triunfo et al., 2024; Zein et al., 2024; Li et al., 2023).

The purpose of this research is to evaluate the efficacy of simply prepared powdered shrimp shell as a biosorbent to remove Cr(VI) from aqueous solutions (Rahman et al., 2023). Batch adsorption experiments were carried out under controlled conditions to investigate the impact of adsorbent dose, contact time, and initial metal ion concentration on Cr(VI) removal efficiency. To understand adsorption behaviour, the experimental data were analysed using Langmuir and Freundlich adsorption isotherm, while kinetic models (pseudo first and second order model) were used to explore the adsorption rate and mechanism. Additionally, FTIR spectroscopy was used to assess changes in functional groups before and after Cr(VI) interaction, providing insight into the nature of the adsorption process (Miah et al., 2022; Abdel-Mohsen et al., 2020; Lima et al., 2024).

Materials and Methods

Raw shrimp shells were collected from a local market in Barishal, Bangladesh, and utilized as the adsorbent in this investigation. After collection, the shells were thoroughly washed to remove impurities and any adhering contaminants. They were then placed in an oven at 60 °C and allowed to dry overnight. After drying, the shells were then crushed into a fine powder with a grinder (Miyako) and strained to ensure uniform particle sizes. The prepared powder was stored in a lidded container for future use.

All of the chemicals were analytical grade, and the source of Cr(VI) was potassium dichromate ($K_2Cr_2O_7$, Darmstadt, Germany). By dissolving an exact mass of $K_2Cr_2O_7$ in deionised water, a 50 ppm stock solution of Cr(VI) was prepared, which was then diluted into working solution. A 0.5% solution of 1,5-diphenylcarbazide (LOBA CHEMIE Pvt. Ltd., Mumbai, India) was prepared in acetone (Johnson Matthey Company, Kandel, Germany) for color development, and 2 M sulfuric acid (Johnson Matthey Company, UK) was used to maintain acidic conditions during spectrophotometric analysis (Khatun et al., 2024).

Batch adsorption was performed using 100 mL of Cr(VI) solution in 250 mL Conical flask. A specific amount of shrimp shell powder was introduced into a solution containing Cr(VI) ions and mixed using an orbital shaker. Samples were collected at fixed time intervals and analyzed for Cr(VI) content by the Nesslerization method (Khatun et al., 2024). The absorbance values were obtained at 540 nm with a double-beam SHIMADZU UV–Visible spectrophotometer (Model No: UV-1900i), using deionized water as the blank. Based on these readings, the adsorption efficiency was determined (Khatun et al., 2024). The procedure was repeated while varying operational parameters, including the amount of adsorbent, the initial Cr(VI) concentration, and the contact time. For each experiment, the percentage of Cr(VI) removal was calculated using the equation:

$$\% \text{ of adsorption} = \frac{\text{Initial absorbance} - \text{Final absorbance}}{\text{Initial absorbance}} \times 100\% \quad (1)$$

The FTIR spectrum of the powdered shrimp shell (before and after adsorption of CR(VI)) was measured using a SHIMADZU FTIR spectrophotometer, Model No-ART (Diamond plate) with ATR method.

Construction of Calibration Curve and Determination of Extinction Coefficient (ϵ) of Cr(VI)

According to the Beer-Lambert law ($A = \epsilon \cdot c \cdot l$), a plot of absorbance vs. concentration should result in a straight line passing through the origin, as illustrated in Fig. 1. The slope of this line is the product of the extinction coefficient (ϵ) and path length (l). Because the path length is 1 cm, the slope directly determines the extinction coefficient. The extinction coefficient (ϵ) at 540 nm is calculated as $0.0076 \text{ L mg}^{-1} \text{ cm}^{-1}$.

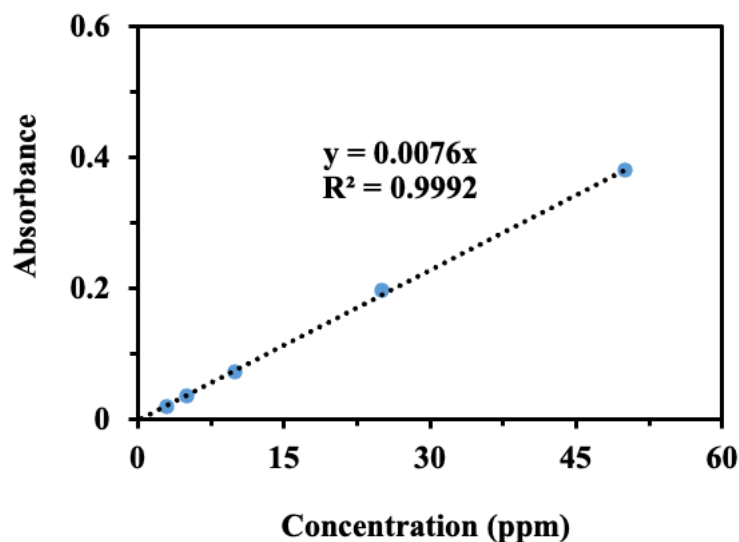


Fig. 1. Calibration curve of Cr(VI) at 540 nm.

Results and Discussion

Effect of Adsorbent Dosage

The purpose of the study was to evaluate the effect of adsorbent dosage on the removal of Cr(VI) from a 5 ppm aqueous solution at 60 min, pH 6.78 and 25 °C temperature. Adsorbent dosages (shrimp shell) ranging from 0.5 g to 3 g were examined and the extent of adsorption was determined using the initial and final absorbance values.

These findings suggest that while increasing the adsorbent dosage initially enhances Cr(VI) removal, there is an optimum dosage (2 g) beyond which the efficiency declines (Fig. 2). The observed reduction in adsorption efficiency at higher adsorbent dosages can be attributed to the possible overlapping of active sites and/or the agglomeration of adsorbent particles, both of which decrease the effective surface area available for interaction with Cr(VI) ions (Rahman et al., 2023).

This emphasizes the significance of selecting an appropriate adsorbent dosage to maximize removal efficiency while keeping material use and operating costs to a minimum. Further studies could focus on understanding the mechanism behind the reduced efficiency at higher dosages and exploring strategies to mitigate this effect (Kayes et al., 2019).

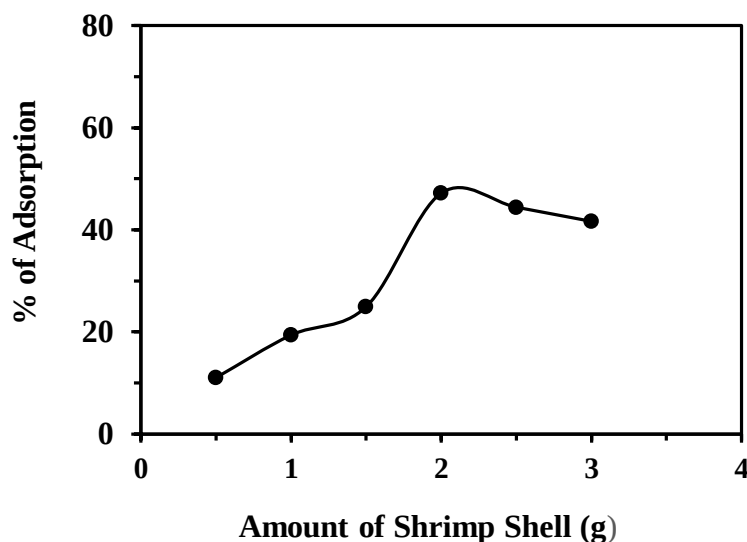


Fig. 2. Percentage of adsorption at different amounts of shrimp shell.

Effect of Contact Time

The removal of Cr(VI) at different contact time demonstrated the dynamic nature of the adsorption process, which was evaluated using a 5 ppm solution and 2 g of shrimp shell adsorbent over contact times of 10, 20, 30, 40, 50, 60, and 70 minutes (Fig. 3). The observed increase in adsorption efficiency with extended contact time can be attributed to the abundance of unoccupied active sites on the bio-adsorbent surface during the initial phases of the process. After 60 minutes of chromium adsorption, a decline in removal efficiency was observed, indicating that the active sites on the bio-adsorbent surface had become saturated. The results suggest that 60 minutes is the optimal contact time for this study, as extending the duration beyond this point does not significantly enhance removal efficiency (Li et al., 2020).

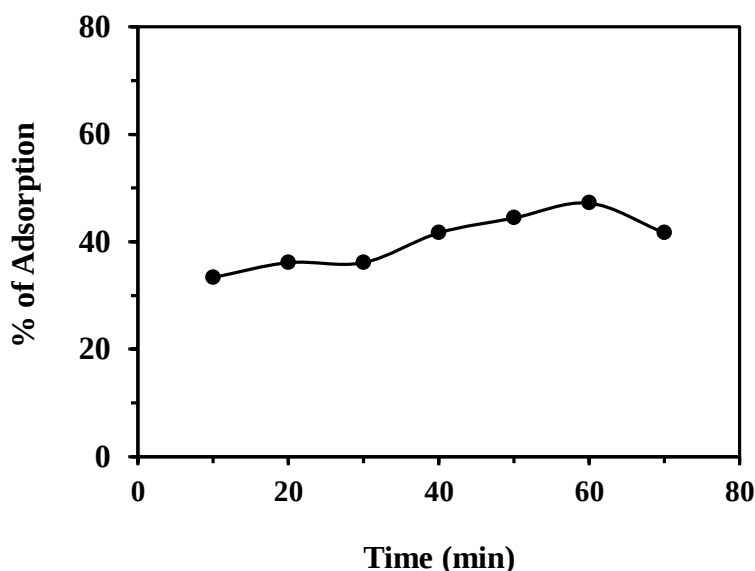


Fig. 3. Percentage of adsorption at various time (min) intervals.

For the adsorption study of a 5 ppm Cr(VI) solution, 2 g of shrimp shell adsorbent was used at different contact times to determine the adsorption capacity (Q_t). Experiments were conducted at room temperature with an initial pH of 6.78. The adsorption capacity at time t , Q_t (mg g^{-1}), for different adsorbents was calculated using Eq. (2).

$$Q_t = \frac{(C_0 - C_t) \times V}{m} \quad (2)$$

Where, m represents the mass of the adsorbent and V , C_0 , and C_t are the volume, initial concentration, and concentrations at time t of the Cr(VI) solution, respectively.

As shown in Fig. 4, equilibrium between adsorption and desorption was nearly reached after approximately 60 minutes. It was also noticed that the adsorption capacity of the shrimp shell enhanced with increasing adsorbent dosage, but beyond a certain point (after 2 g), it began to decrease.

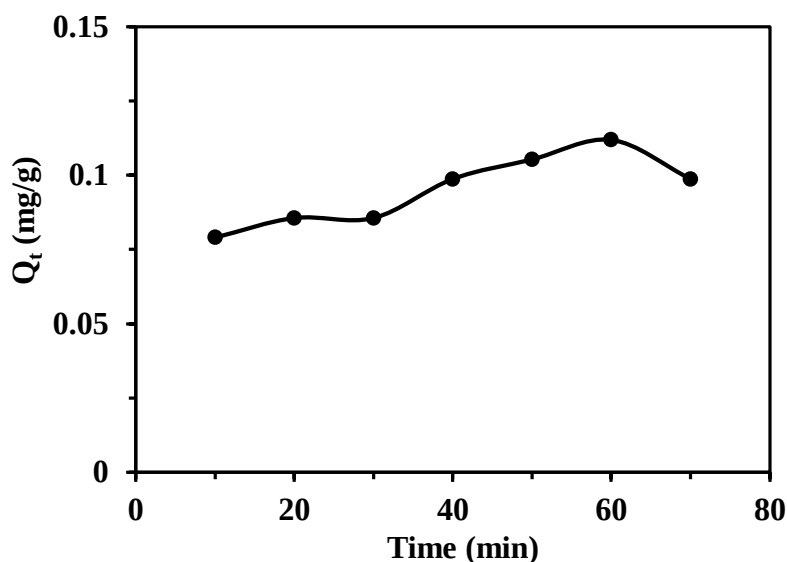


Fig. 4. Effect of contact time on the adsorption of Cr(VI).

Effect of Concentration

The influence of initial concentration of Cr(VI) on the adsorption was examined using 2 g of shrimp shell at different concentrations i.e. 5 ppm, 10 ppm, 25 ppm, and 50 ppm. Fig. 5 demonstrates that adsorption efficiency declines as Cr(VI) concentration increases, reflecting an inverse relationship between these variables. These decreases in adsorption percentage may be result from the saturation of the adsorbent's binding sites, where the rising concentration of Cr(VI) ions exceeds the adsorbent's capacity to capture them. Beyond a certain concentration, the adsorption sites become occupied, and the remaining Cr(VI) ions are unable to bind effectively to the adsorbent (Mukhlisah et al., 2020; Kayes et al., 2024). It was observed that 2 g of adsorbent shows efficient adsorption at lower concentrations, increasing the adsorbent dosage or modifying the adsorbent properties may be necessary to maintain high removal efficiencies at higher concentration.

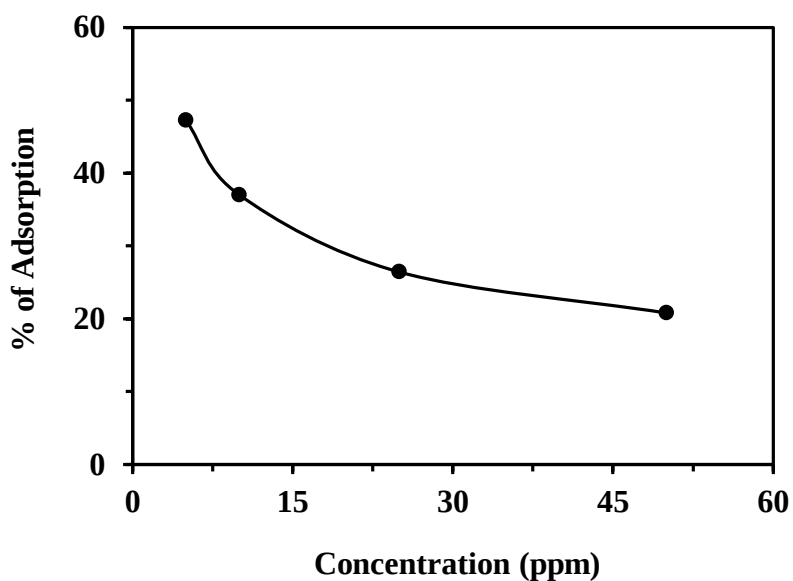


Fig. 5. Percentage of adsorption at different concentration of Cr(VI).

For shrimp shell adsorbents with various initial concentrations (5, 10, 25, and 50 ppm), the extent of adsorbed adsorbates Q_e (mg g⁻¹) at equilibrium condition (60 min) was determined by using eqn. (3).

$$Q_e = \frac{(C_o - C_e)V}{m} \quad (3)$$

In this equation, m represents the adsorbent mass, while V , C_o , and C_e denote the volume, initial concentration, and equilibrium concentration of the Cr(VI) solution, respectively. As demonstrated in Fig. 6, the adsorption capacity (Q_e) was observed to increase with increasing equilibrium concentration (C_e) of the Cr(VI) solution.

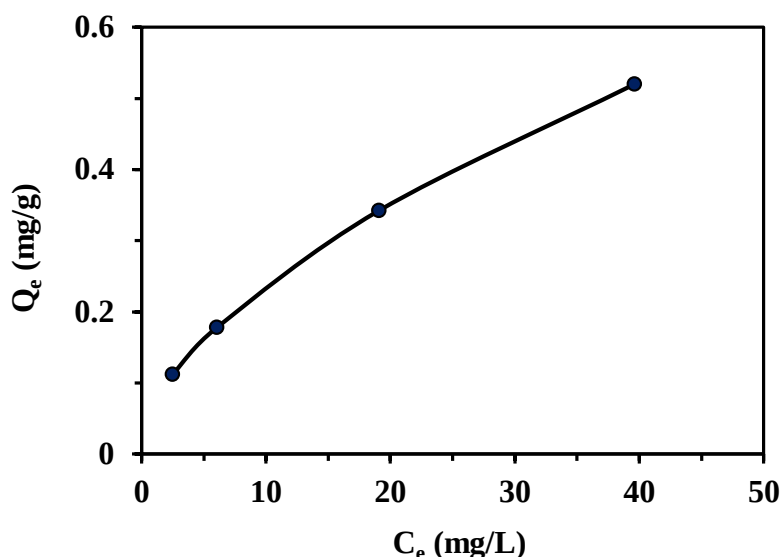


Fig. 6. Effect of equilibrium concentration on the adsorption of Cr(VI).

Kinetic and Isotherm Studies of Cr(VI) Adsorption

Isotherms Study

To describe experimental adsorption data, a variety of equilibrium adsorption isotherm equations are commonly used. Using various adsorption isotherms, the highest adsorption capacities and adsorbate affinity to adsorbents can be predicted to better understand surface properties. As a result, it is critical to identify the adsorption isotherm that best fits the data collected. Freundlich and Langmuir isotherm models are two popular mathematical models. The Langmuir model assumes that all adsorbent sorption sites are monolayer covered and uniformly distributed. On the other hand, the Freundlich isotherm model implies that all adsorption sites are heterogeneous and the coverage is multilayer (Musah et al., 2022; Ray et al., 2020).

The experimental data fitted in Langmuir and Freundlich isotherm are explored in Figures 7 and 8 respectively. All the parameters of Langmuir and Freundlich isotherms were calculated and demonstrated in Table 1 and 2. The correlation coefficient (R^2) value obtained from experimental data is in good agreement with Freundlich isotherm model than the Langmuir. This well fit of the Freundlich model recommends that the adsorption predominantly occurs through multilayer coverage on heterogeneous surfaces.

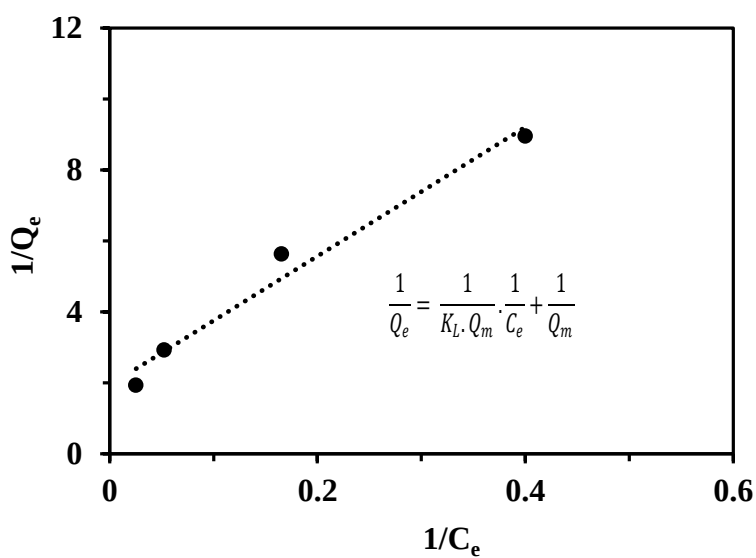


Fig. 7. Langmuir isotherm for adsorption of Cr(VI).

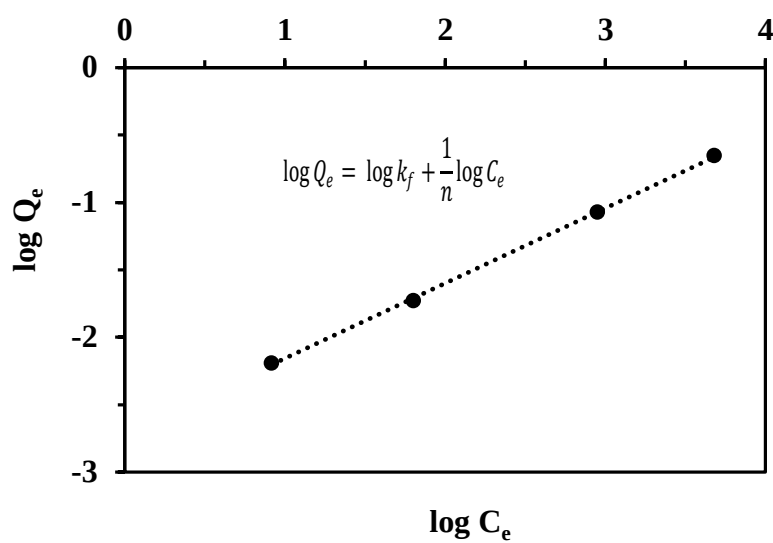


Fig. 8. Freundlich isotherm for adsorption of Cr(VI).

Table 1. Parameters obtained from Langmuir isotherm model.

Adsorbent	Intercept	Slope	$Q_{\max}$ (mg/g)	K_L (L/mg)	R^2
Shrimp shell	1.9338	18.173	0.5171	0.106	0.974

Table 2. Parameters obtained from Freundlich isotherm model.

Adsorbent	Intercept	slope	k_f	n	R^2
Shrimp shell	-2.7147	0.5579	0.002	1.79	0.9996

Kinetics Study

The kinetics for the adsorption of Cr(VI) on the surface of shrimp shell was investigated by using pseudo-first and pseudo-second-order kinetic models. Table 3 summarizes the findings of the kinetic parameters for both models, which were obtained from the plots of $\log(Q_e - Q_t)$ vs. t and t/Q_t vs. t respectively. The correlation coefficient value for pseudo-second-order equation is 0.9784 whereas, it is 0.893 for the pseudo-first-order. The experimental results are explored in Figures 9 and 10. The kinetic parameters are summarized in Table 3. These results suggest that the adsorption kinetics of Cr(VI) on the shrimp shell are better explained by the pseudo-second-order kinetics, implying that chemisorption may be the predominant mechanism (Gautam and Chattopadhyaya 2016).

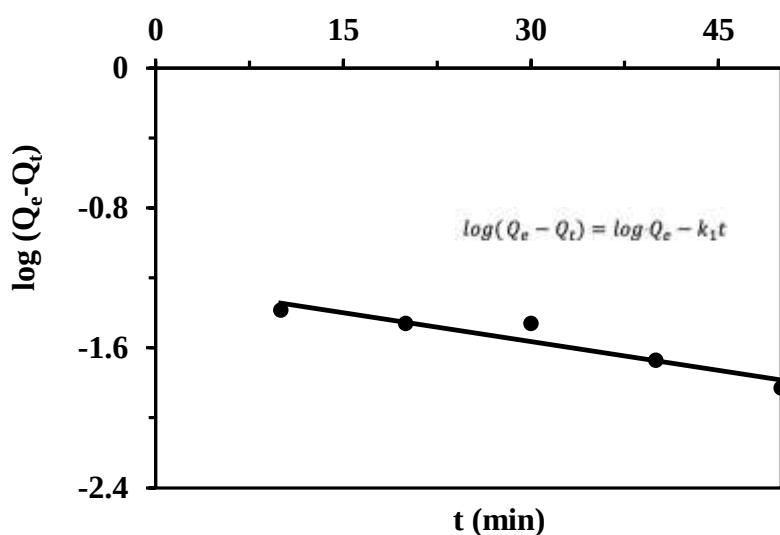
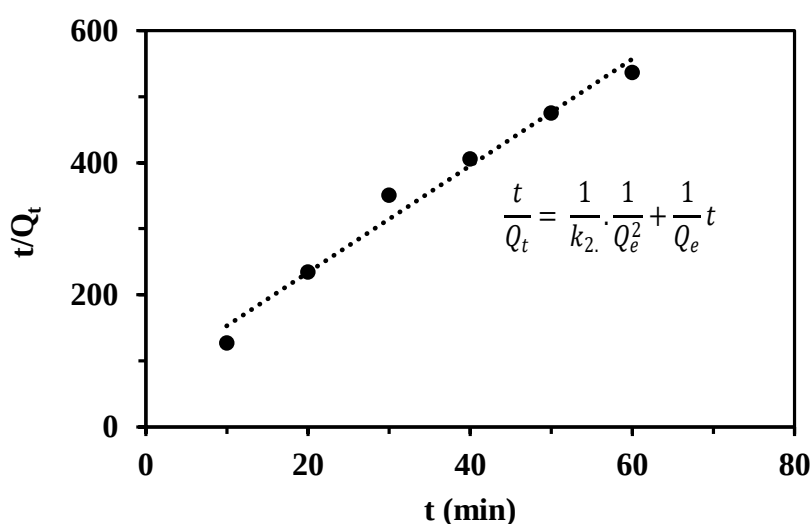
**Fig. 9.** Pseudo-first order kinetic model for the adsorption of Cr(VI) on shrimp shell.**Fig. 10.** Pseudo-second order kinetic model for the adsorption of Cr(VI) on shrimp shell.

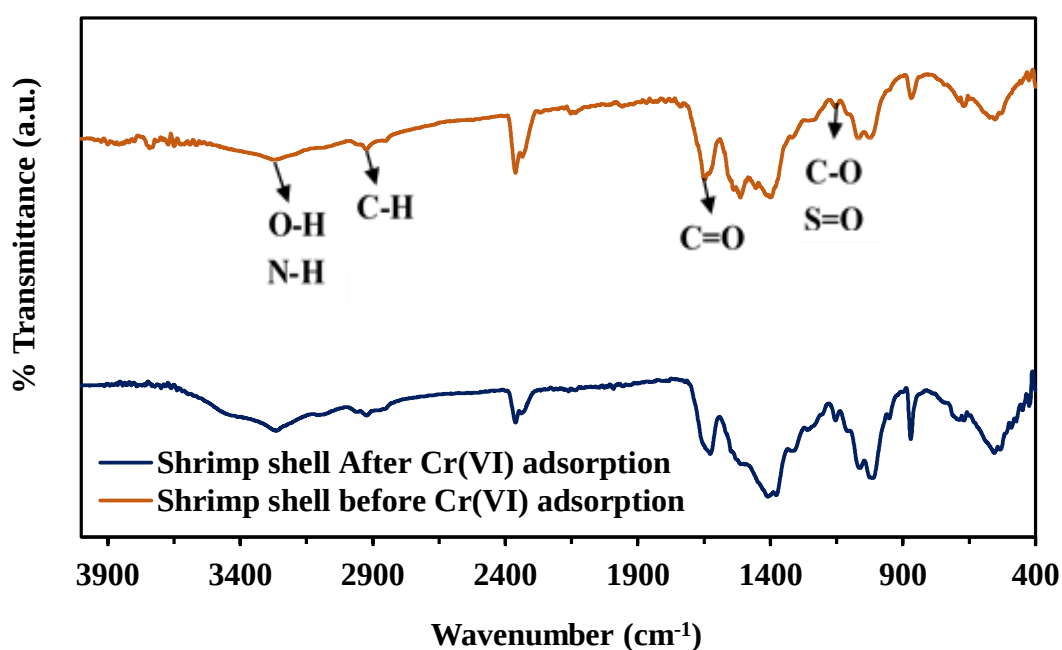
Table 3. Kinetic parameters for the pseudo-first and pseudo-second-order models.

Pseudo-first-order model				Pseudo-second-order model			
Slope	Intercept	k_1	R^2	Slope	Intercept	k_2	R^2
-0.011	-1.2333	0.011	0.893	8.0773	71.976	0.906	0.9784

Characterization of the Adsorbent (Shrimp Shell) by FTIR Spectroscopy

The shrimp shell was examined by FTIR over the range of 4000 to 400 cm^{-1} to detect functional groups responsible for Cr(VI) adsorption and provide understanding of the interaction mechanism between the adsorbent and the adsorbate.

Fig. 11 demonstrates that the shrimp shell contained many kinds of functional groups. Before Cr(VI) Adsorption, a large peak was observed at 3272.49 cm^{-1} for O-H Stretch and N-H groups but it was shifted to 3261.02 cm^{-1} in spectrum of shrimp shell after Cr(VI) adsorption, indicate strong hydrogen bond or complex formation with Cr(VI). The peak at 2923.87 cm^{-1} was correlated to C-H stretching, and the peak around 1646.29 cm^{-1} was related to C=O. Changes in the fingerprint region further support the adsorption process. In Spectrum of shrimp shell before adsorption, a peak at 1154.91 cm^{-1} attributed to C-O or S=O stretching vibrations was present, but it disappeared in Spectrum after Cr(VI) adsorption, implying that these functional groups interacted with Cr(VI) during the adsorption process. Several new peaks at 1315.60, 1064.53, 1013.60 cm^{-1} have been appeared and several peaks at 2138.38, 1513.38, 1409.57 cm^{-1} have been disappeared in FTIR spectrum of shrimp shell after adsorption. This observation supported the adsorption of Cr(VI) onto the shrimp shell (S et al., 2016; P.S.Kalsi; Yasmeen et al., 2016; Eddy et al., 2020).

**Fig. 11.** Overlap of FTIR spectra of shrimp shell before and after adsorption.

Conclusions

The study demonstrates that shrimp shell is a fruitful adsorbent for removing Cr(VI) from water, emphasizing its green and sustainable properties. Hexavalent chromium (Cr(VI)) removal efficiency by adsorbent (Shrimp shell) is found to change with various physiochemical parameters e.g. adsorbent dosage, reaction time, and concentrations. It has been observed that shrimp shell (2 g) was able to remove Cr(VI) (concentration, 5 ppm)

from aqueous solution about 47.22% in 60 minutes. The FTIR spectra of shrimp shell before and after adsorption explored the successful removal of Cr(VI) by shrimp shell. The experimental data fits the Freundlich adsorption isotherm model quite well, suggesting the multilayer interactions on a heterogeneous surface. Kinetic analysis revealed a better fit for the pseudo-second-order model, suggesting chemisorption as the dominant mechanism, which involves specific binding interactions.

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Community Perceptions on Flood Recovery and Knowledge Gaps Towards Flood Resilience in Gaibandha District, Bangladesh

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Abstract

Floods are the most frequent and devastating hazards in northern Bangladesh. The unpredictable upstream influx of river water and heavy rainfall cause rivers to overflow, floodplains to become inundated, and the riverine community to become vulnerable to floods. Fulchhari Upazila in Gaibandha District is particularly prone to frequent flood hazards. This study aims to identify the impacts of floods, post-flood recovery efforts, and knowledge gaps in Fulchhari Upazila to enhance community resilience to flood hazards. A semi-structured questionnaire (N=150) survey was used to fulfill these objectives. In addition, Key Informant Interviews (KII) and Focus Group Discussions (FGD) were conducted to triangulate and validate the collected household data collection and to identify knowledge gaps. The acquired data indicate the major adverse impacts of floods in the Fulchhari Upazila region as follows: house inundation (78%), transportation problems (88.67%), water crisis (64.67%), crop damage (54%), and communication disruption (43.33%). To cope with these impacts, people have taken measures such as seeking shelter on rafts and using water purification methods. They also get benefit from the government and NGO, which comes in the form of relief goods (44.67%), recovery and reconstruction efforts (58%), rehabilitation (19.33%), embankments (94%), water reservoirs (23.33%), economic support (52.67%), and evacuation assistance (15.33%). For proper flood management, respondents have called for the provision of flood shelters, employment opportunities, and floodproofing measures. Eighty-two percent of the respondents have preliminary knowledge about flood recovery, while 18% are completely unaware. The knowledge gap in Disaster Risk Reduction (DRR) is also significant, with 78% attributing it to the lack of standard policies. For sustainable improvement, 70% of respondents believe that providing better job opportunities is essential, and 58% agreed that river excavation could be an effective measure. Almost all respondents demand a durable embankment facility. In addition to proper recovery initiatives, enhancing awareness-raising programs, training, volunteer involvement, management systems, and proper education is crucial for building a resilient community. The findings and discussion of this study will offer guidelines to policymakers, aiding in the development of a sustainable and effective risk management strategy for the area.

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Keywords: Flood, Community perception, Hazard, Resilience, Bangladesh

1. Introduction:

Since prehistoric times, floods have been among the most perilous of all known calamities. Colonies and towns were more susceptible to flooding because people were constantly drawn to the river's channels for many reasons, such as rich land, cheap transportation, and greater access to water. Floods are among the most recurring hazardous disasters in the present global setting. Approximately 42% of the 10,320 natural disasters that occurred worldwide over the last three decades (1990-2020) were classified as floods (IEP, 2021). Floods are accountable for one-third of the overall economic losses and half of all fatalities caused by natural disasters (Kellens et al., 2013). The social and economic dimensions of the populace are profoundly impacted by floods, which also claim the most lives of any natural occurrence (Dilley et al. 2005; Irshad, 2024). It remains a significant concern in numerous regions across the globe as the most economically detrimental and devastation-inducing natural hazard (Kabir and Hossen, 2019).

Bangladesh may be rated first if anything is done to assess the devastation caused by floods. The region's geographical characteristics are significantly attributable to recurrent flooding. 75% of the nation's land area is no higher than 10 meters above mean sea level, and an even greater 80% of the land area is designated as a floodplain (BBS, 2021). Flooding affects Bangladesh practically every year. Bangladesh suffered from catastrophic flood events in 1988, 1998, 2007, and 2017, affecting almost 60% of the nation. The effects of the floods can be felt throughout various economic and social sectors, leading to increased death rates, poverty, agricultural land loss, environmental refugees, and communication breakdowns. People residing in areas close to rivers and char lands lack the necessary skills to adequately cope with the consequences of natural disasters. This is because of poor socioeconomic conditions and the demand for greater adaptation options (Mitu Akter et al., 2024). Bangladesh is a relatively small country located at the Ganges-Brahmaputra Delta plain, and most of its population lives in the floodplain of the Ganges-Brahmaputra-Meghna river system (Ganges Delta). This river system has a catchment area of 1.7 million square kilometers and discharges about 1350 cubic kilometers of water every year (Forootan et al., 2015). Annually, approximately 35% of the nation's land area is submerged for 5-7 months (Kabir and Hossen, 2019).

Gaibandha district is situated in northern Bangladesh. The average precipitation of this region is nearly 250 mm. The mighty Brahmaputra crosses through this district. The slope of the river is relatively low, and the surrounding areas are exceedingly flat. In most years, the Brahmaputra's water level begins to rise sometime between the middle of April and the beginning of May, and it reaches its potentially hazardous peak in the summer months of July and August. However, the Ganges starts to rise in mid-May or early June and reaches its highest point in August or September (Sarkar et al., 2022). A northward shift of the monsoon trough is linked to this heavy precipitation, which has generated active monsoon conditions in the Brahmaputra basin. A region encompassing the lower subbasins adjacent to the northern border of Bangladesh receives the precipitation (Hossain et al., 2019).

Southeast Asia, Peninsular India, eastern Africa, and the northern half of the Andes are just a few of the regions that may see an increase in water-related disasters, particularly floods, in the coming years (Hirabayashi et al., 2013). The global flood risk is projected to increase by approximately 187% by 2050 (Arnell and Gosling, 2016). Considering the global alarming threats of flooding, many scholars and scientists have studied and researched this topic. Kuang and Liao (2020) tried to construct a relationship between flood experience and flood resilience. In their

conclusive remarks, they stated that flood-related knowledge has the potential to guide flood management and other actions, its application is often hindered by obstacles such as lack of information and resources, attitudes towards it, social capital constraints, and policy barriers (Kuang and Liao, 2020). The researcher devised the Learning from Floods (LFF) framework to elucidate the learning process derived from personal flood encounters and their consequential impact on flood resilience.

With a particular emphasis on gender, Chisty et al. (2022) conducted research in Sirajganj to determine the level of community flood resilience. The study analyzed both qualitative and quantitative data. A linear questionnaire was used, with a five-point Likert scale to capture quantitative data. Regarding being resilient to disasters, the survey indicated that women in the community need to prepare more than men. The study suggests that when evaluating the resilience of communities to disasters and implementing interventions to enhance that resilience, a gender-sensitive approach should be considered (Chisty et al., 2022). It is mentioned in this study that Gaibandha can be categorized as a highly vulnerable region (Ahmed et al., 2018). In addition to examining the characteristics, severity, susceptibility, and effects of different kinds of catastrophes, Rahman et al. (2017). In the last remarks, people's susceptibility to catastrophes is growing daily, and the creation of policies on disaster management is urgently needed (Rahman, 2017). Lee et al. (2021) evaluated the vulnerability of different regions of Bangladesh regarding their socioeconomic status, health conditions, and ability to cope with challenges. The study findings suggest the presence of susceptible areas in the riverine regions in the northwest, floodplains of the northeast, and regions in the southwest (Lee et al., 2021). From the literature, it is clear that floods are recognized as one of the most disastrous calamities throughout the globe, and different approaches have been adopted by different scholars to either reduce the damage or assess the damage. In the case of Bangladesh, recent work on flood risk assessment is sparse, though a few researchers are showing interest in spatial assessments of flood distribution (Islam and Hasan, 2023; Dewan, 2013; Haque et al., 2021; Hoque et al., 2019). Being a highly flood-prone region, Fulchhari Upazila, Gaibandha needs exposure so that insights about the condition, damage, people's perception, level of resilience, knowledge, and structural gaps of flood risk can come to the attention of the governing bodies and policymakers. But effectively, no such work has ever been conducted in this region. After considering this research gap, it is urgent to conduct this study in this particular area.

Flood damage assessments are essential to create efficient and affordable flood mitigation strategies and flood preparation plans (Singh and Dhanya, 2024). This study is novel in that it integrates community perception, post-flood recovery practices, and knowledge gap analysis within a highly flood-prone and under-researched region of northern Bangladesh. Unlike previous studies that focus primarily on vulnerability assessment, this research emphasizes the linkage between local knowledge deficiencies and resilience-building, providing actionable insights for policy and community-level interventions. The main objectives of this study are as follows: 1. assessing the impact of floods in the study area, 2. revealing the actual socio-demographic picture of the Fulchhari Upazila, 3. assessing the people's perception of flood preparedness and recovery, 4. identifying the existing methods adopted by the community to cope with flood damage, 5. revealing the degree and intensity of the knowledge gap and resilience about Disaster Risk Reduction (DRR) among the victims, 6. portraying the victims' demands that they believe can reduce the existing vulnerability, 7. Providing practical recommendations by considering the victims' comments. The study aims to leave some valuable findings and recommendations that will help administrators and policymakers build sustainable plans to counter recurring floods.

2. Study area:

Having an area of 314 square kilometers, Fulchhari Upazila ranges from 25°23'N to 25°10'30" N and 89°45'30"E to 89°33'30"E. The Upazila has a total population of 1.65 million. The Upazila contains 7 unions; among them, Udakhali, Kanchipara, and Gojaria Unions are the worst sufferers of the flood. The Brahmaputra River and the Ghghat River run across the region. The Brahmaputra is a basin in Bangladesh prone to flooding every year during the monsoon season. Both rivers become overloaded with huge amounts of inflows during the monsoon. Due to the region's extremely flat topography, river overflows encounter no obstructions; consequently, monsoon flooding occurs frequently in this area. Over the last two centuries and fifty-five years, the Brahmaputra-Jamuna River has undergone significant changes in course, as supported by indications of extensive avulsion from 1776 to 1850 and a more general westward migration of the Jamuna channel belt since that time (Best et al., 2007). This shifting nature of the river channels makes the study area more susceptible to recurring flood events. Given the floods of 2017 and 2019 in this region, this is highly relevant for flood risk assessment. Every year, devastating floods occur here, resulting in irreparable losses and damages.

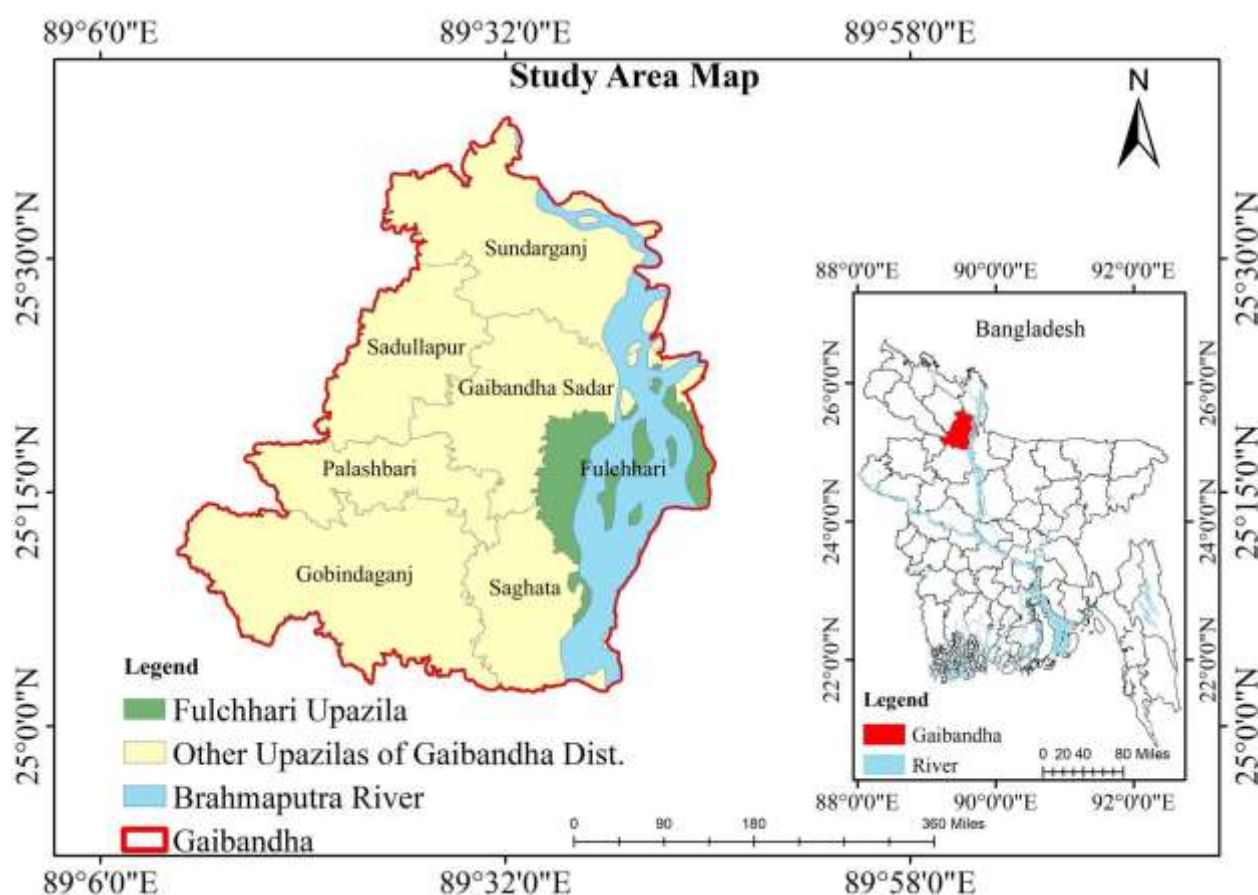


Figure 1: Study area map of Fulchhari Upazila, Gaibandha

3. Materials and Methods:

The study is designed so that both primary and secondary data can be incorporated into the study. Primary data were collected using qualitative and quantitative approaches. Informal interviews, key informant interviews, and focus group discussions were conducted among the victim community for a more detailed data evaluation. It is worth mentioning that in the FGDs, the

target population was asked different questions regarding the natural hazards, livelihood, adverse effects, agricultural production, income generation, coping strategies applied, and recovery status in the locality. Five FGDs were arranged, and more than 18 participants actively participated in each group. The FGDs helped to reveal insights into floods and their adverse effects, livelihood patterns, income generation, and adaptation techniques, as well as the present recovery status, recovery gaps, and initiatives in aspects of post-flood recovery in the affected sectors. Sufficiently experienced people were selected as appropriate candidates for Key Informant Interviews (KII). 25 Key Informant Interviews (KII) were conducted with different UP members of respective unions, volunteers of the Red Crescent Society, Gono Unnoyon Kendro, SKS Foundation, member, CARE Bangladesh, Proshikha, UNO office, a respective member of the Disaster Management Committee, and school teachers. The comments of the participants were taken into consideration and were incorporated into the analysis. The questionnaire survey was a major part of the assessment, from which the quantitative data were generated. The questions focused on the agricultural systems, general demographics, and socioeconomic characteristics of the selected community. A stratified sampling procedure was used where 3 unions were chosen based on their vulnerability to flooding. The sample size was determined from the following equation (Cochran, 1997).

$$SS = \frac{Z^2 \times P \times (1-P)}{C^2}$$

Level of confidence = 95%; Chi-square level of significance 95%, $Z = 1.96$; percentage picking a choice, expressed as a decimal, $P = 0.5$ (male & female base); confidence interval (in decimal), C (e.g., $0.04 = \pm 4$). According to Eq. (1), the required sample size is 150. From each of the unions, 50 respondents were taken into consideration. A wide range of secondary data was collected from literature reviews of various books, journals, and encyclopedias. Statistical data were also collected from the Union Parishad, Upazila Parishad, and journals. To simplify and summarize the data, different descriptive statistical operations were conducted on the acquired data. Numerous diagrams, charts, graphs, and tables are used to present significant data. Microsoft Office Excel and SPSS software packages were used for statistical tests and analyses. Different required maps are presented through ArcGIS software.

4. Results and Discussions:

4.1 Respondents Demography: A total of 150 respondents took part in the questionnaire survey. The respondents were selected randomly (50 from each) from three unions, namely the Kanchipara, Udakhali, and Gojaria Unions. According to the age of respondents most of the respondents are between 42 and 48 years old (Table 1). This kind of specific age-ranged participation occurred because nowadays, the younger community is leaving the villages for better jobs and secure lifestyles. Based on the educational status, 28.67% of respondents completed their studies up to the primary level, which is the majority. Shockingly, 23.33% of the respondents have no formal education, and only 14.67% managed to reach a higher secondary level. When the respondents were asked about their poor educational status, they blamed poverty. Jahangir Mia, a 40-year-old illiterate farmer, said, "*I started working with my father at the age of 10, I, along with my brothers, had to work in the crop field to manage our family expenses.*" Talking about occupation, the highest percentage (45.33%) of respondents are farmers, and 22% of the respondents claimed to be self-employed businessmen. Mainly running tea stalls, small grocery shops, and exporting crops to large cities are cited as businesses. From the demographic summary, it can be said that the study area is an agro-based society. In the past, the tendency to acquire formal education was lower. But in today's scenario, the ratio of participation in school is seeing an upward trend. Lack of education

has confined most of the people of the community to select only some limited occupations. Among the participants, almost 37% of respondents have been affected 5 to 8 times by floods in their living tenure, followed by 21.33% who have seen catastrophes 8-11 times in the study area. Even some individuals have seen catastrophic floods more than 11 times in their lifetime. This gives a view of the recurring frequency of floods in this region. Thus, based on the analysis of the demographic data, the investigated community can be referred to as a rural farming community vulnerable to disaster risk.

Table 1: Demographic characteristics of the respondents

Characteristic		n (N=150)	%
Gender	Male	85	56.77
	Female	65	43.33
Age (Years)	<18	0	0
	18-24	23	15.33
	24-30	17	11.33
	30-36	23	15.33
	36-42	16	10.67
	42-48	29	19.33
	48-54	19	12.67
	54+	23	15.33
Education	No formal education	35	23.33
	Up to Primary	43	28.67
	Up to Secondary	33	22.00
	Up to Higher Secondary	22	14.67
	Graduate	8	5.33
	Post Graduate	9	6.00
Occupation	Govt. employee	23	15.33
	Farmers	65	43.33
	Self-employed (Business)	33	22.00
	Student	12	8.00
	Private employee	8	5.33
Distribution	Kanchipara Union	50	33.33
	Udakhali Union	50	33.33
	Gojaria Union	50	33.33
Living Period in the study area	<5 Years	12	8.00
	5-15 Years	29	19.33
	15-25 Years	77	51.33
	>25 Years	32	21.33
Number of flood events affected	<2 Times	9	6.00
	2-5 Times	41	27.33
	5-8 Times	56	37.33
	8-11 times	32	21.33
	>11 times	12	8.00

4.2 Impacts of the Flood Hazard: Various floods have devastated Bangladesh, destroyed homes, and killed many people. The study revealed that floods have a multidimensional impact on the economic and social life of the victim community. They damage structural facilities and hamper the social well-being of the affected population.

4.3 House Inundation: Almost 78% of the respondents claimed their houses got inundated during the flooding (Figure 2). Many of the houses get inundated every year, and some of them get inundated during excessive flood events. During the survey, it was observed that houses are built in areas susceptible to flood inundation and very close to the river course. The embankment facility is not that impeccable in the affected zone. Most importantly, the river does not remain bound in any particular channel during the monsoon. It shifts its channel nearly every year; thus, the inhabitants cannot predict the safer zone for house construction. Many of the victims claimed that their existing house was inherited from their ancestors, and in the past, the river course was far away from their present residence. Some of the victims want to relocate their present residence but do not have the financial ability to acquire new land or houses. Joynal Sikder, a 50-year-old riparian farmer, said, "We have been living on this land for years. My father built this house. even 20 years ago, we used to feel safer from flooding, but now almost every house goes under. Our misery is beyond description." The flat terrain of the region is the most significant cause of the house inundation problem. The river channel exposes numerous bars and usable land during the dry season. The landmasses offer perfect cultivation and livestock rearing facilities, attracting people to build their houses near the river course. Again, the traditional house structure of this region is also responsible for this problem. Most of the basements of the houses are not high enough to resist floodwater, which makes the houses inundated.

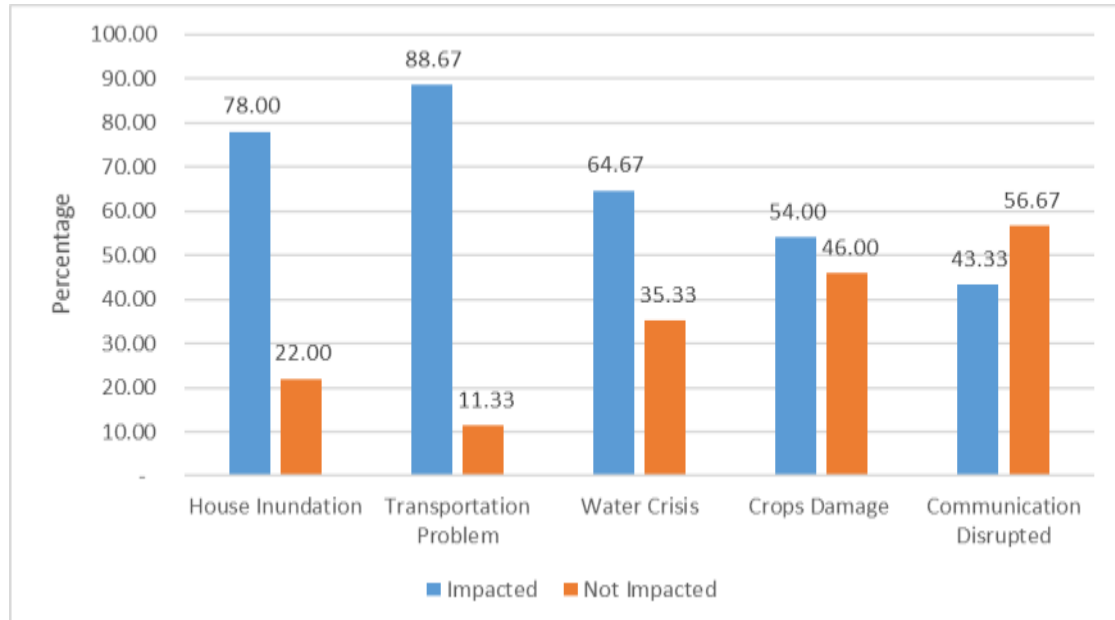


Figure 2: Impacts of flood hazards in the study area (Source: Field Survey-2020)

4.4 Transportation Disruption: 88.67% of respondents claimed that transportation facilities are badly hampered during flooding (Figure 2). Most of the roads and paths of the investigated region are not elevated more than 2 yards above the surroundings. Thus, they easily get flooded during floods. People also claimed that some roads get inundated even in normal seasonal monsoons. Boats and rafts become the only means of transportation in flood-affected regions. Zahir Sheikh, a middle-aged resident of Fulchhari Union, said, "During monsoon, almost 70-80% of the local

roads go underwater. The paved roads also get damaged due to the prolonged inundation. Our urge to the government is to elevate the heights of the roads." Elevated roads can also act as safer places to shelter flood victims. Inundation of the roads also deteriorates the relief and evacuation operations. Not all the affected families have the ability to own a boat. Thus, they depend on rafts, which are mainly made of banana plants or bamboo, which are not durable and also difficult to navigate. Disruption of the transportation facility leads the victims to a miserable time period as it becomes difficult to manage the goods of daily use. The historical flood data can be analyzed to estimate the maximum heights of the water level during floods, and roads should be rebuilt and designed considering the findings.

4.5 Drinking Water Crisis: Besides the multitude of susceptibilities, water supply complications intensify significantly in the event of a flood (Shimi et al., 2010). Indeed, this holds true for the sample group under study. At least 64.7% of people who took the survey said they suffer from a water crisis when floods occur (Figure 2). The main source of drinking water supplies in the region is tubewells. It has been seen that tubewells are community-based, and many people collect drinking water from a single tubewell. Thus, any disturbance in the tube wells can disrupt the water supply for multiple families, which makes the population vulnerable to a water crisis. A tubewell has been tried to be constructed on a higher basement, but the respondents claimed that it is not uncommon for tube wells to get inundated during a flood. Sakhawat, a 35-year-old school teacher, said, *"The nearest tube well from my house is 250 yards away, and it gets inundated during the monsoon every year. Our sufferings know no bounds due to the water crisis. I have to use rafts to collect drinking water. We cannot boil flood water due to the lack of fire facilities. Although chemical pills are available for water filtration, we are skeptical about their efficacy."*

4.6 Crop Damage: A significant contributor to the economies of most developing countries in Asia is agricultural production, particularly rice production, which provides producers with the majority of their income (Shrestha, Kawasaki, and Zin 2021). Agricultural production also decreases during flooding. In the study area, 54% of the respondents claimed crop damage during floods (Figure 2). Almost all farmland gets inundated during flooding, so the damage should have been higher. According to the farmers, they do not cultivate any crop during the monsoon season. Thus, the huge agricultural land remains barren for 5-6 months. Amir Ali, a farmer of 30-year-old farmer, said, *"My ancestors attempted to cultivate our arable lands year-round; however, the hardships they endured during the monsoon were intolerable; consequently, we have lost interest in doing so during the rainy season. I have adopted an alternative occupation as a fisherman during the rains."* The practice of flood-tolerant crop cultivation is gaining attention among the farmers, but support, training, and subsidies are required to become sustainable in monsoonal crop production.

4.7 Communication Disruption: One of the most fundamental and potentially most consistent attributes of all catastrophes is their profound effect on relationships (Kaniasty, 2020). Communication disruption refers to a circumstance in which the smooth operation of essential societal processes is interrupted (Ten Brinke et al., 2017). Communication disruption is common in every kind of disaster. During flooding, people have to seek safer places and, commonly, they have to leave their kith and kin. Sometimes, due to flooding, many families are reported to be isolated for days. Hampering social communication also halts the process of proper assistance distribution. In the study region, 43.33% of the respondents reported that they face communication disruption during flooding (Figure 2). In an FGD, participants claimed that due to inundation the electrical

connection gets disrupted, and cell phones become dead thus they can only communicate with others with small boats and rafts. Lack of communication can be lethal. It often happens that during floods, people become sick for many reasons, such as sanitation problems, hunger, and lack of pure water. In these cases, without access to emergency medical care, the affected person may find themselves in a risky scenario. Regular patrolling during flood situations can be a practical solution to these problems.

4.8 The practices to manage flood impacts: Best practices for managing flood impacts are such processes that implement proactive, well-targeted investments-including infrastructure investments, technological advancements, capacity enhancements, system and behavior modifications, management practice adjustments, and risk transfer via Insurance. Integrated flood risk management offers prospects for mitigating future expenses associated with relief and recovery. Additionally, it promotes fiscal stability and the enduring welfare of communities amidst the escalating variability of climate conditions (Mai et al., 2020). Talking about the study area, only a few indigenous techniques are adopted by the victim community. In the name of individual management strategies, they follow limited processes like taking shelter in safer places, purifying water by any means, etc. Thus, during an emergency, the afflicted community endeavors to provide for only its most fundamental requirements. The acquired data reflects that 45% of the respondents move to a safer place, like taking shelter on rafts, boats, or on higher roads. 34% of the population uses only indigenous procedures to purify the water (Figure 3). Shockingly, the tendency to adopt sustainable risk-reduction steps is exceedingly low among the population. Knowledge gaps and lack of resilience are the main features that contribute to such behaviors among the victims. Additionally, financial constraints hinder individuals from implementing improved infrastructure and enhancing their capabilities. Imram Hossain, a 25-year-old tea seller, said, "I want to raise the basement of my house, *but where is the fund?*". Thus, proper training and easy loan facilities can make the traditional practices more sustainable.

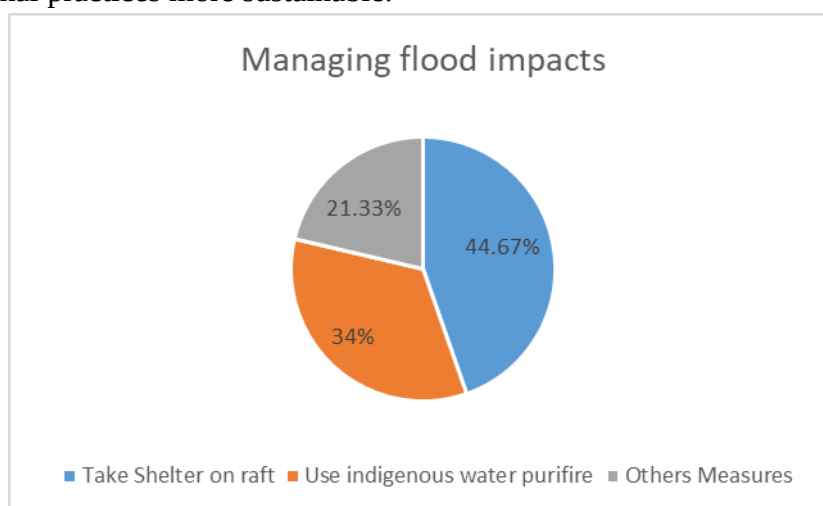


Figure 3: The practices to manage flood impacts (Source: Field Survey-2020)

4.9 The government, the NGO, or others' initiatives/assistance to manage the flood impacts: Undoubtedly, the most important aid that the affected community can get is aid from the government. Every year, millions of taka are budgeted for relief and disaster infrastructure development. According to the Department of Disaster Management from 2018 to 2023, the government has spent 155742.13 lakh taka to develop flood shelters throughout the country (ddm.gov.bd). In the study area, we can see that about 90% of people get direct relief privileges

from the government. 94% benefit from government. established embankments; almost 23% get water supplies, whereas 77% don't get this assistance. From government initiatives, about 58% and 19.33% of people get recovery and rehabilitation opportunities (Figure 4). Here, we can also see that almost 81% of people are deprived of rehabilitation programs by the government. Hence, according to many respondents, although the government is trying to reduce flood losses, assistance is inadequate. Some of them also blamed the local government's inefficiency. Sharmin Begum, a housewife, claimed, " We know that much of the relief goods are provided by the government, but it happened many times that we, the actual needy, *do not get any of the aid. Biased distribution by the local government is the main cause of our misery.*"

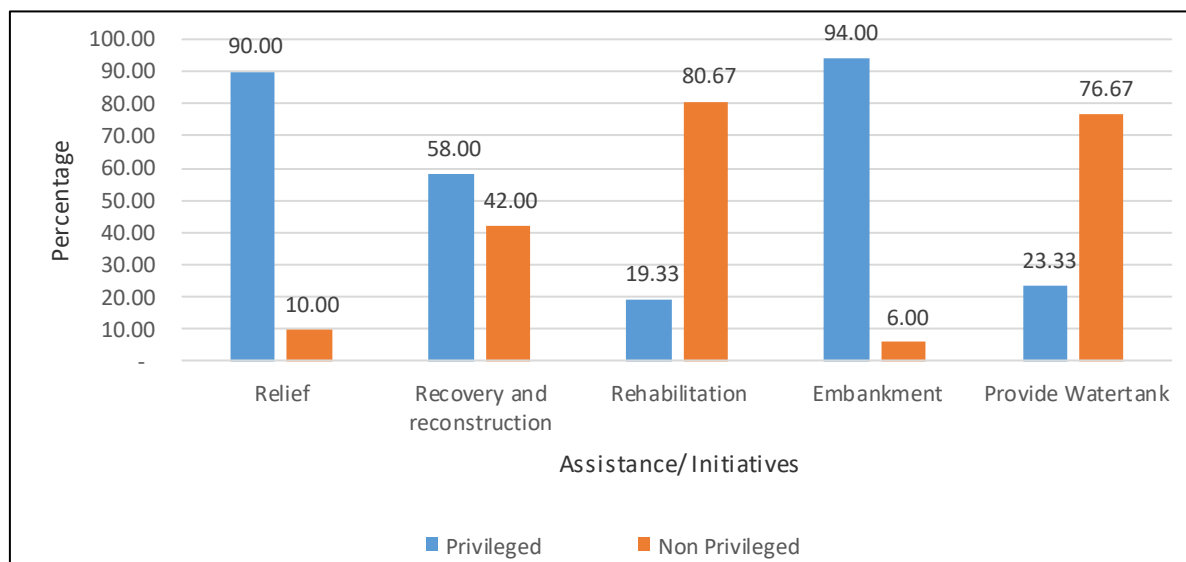


Figure 4: The government's initiatives or assistance to manage flood impacts (Source: Field Survey-2020)

While continuing to shape humanitarian emergency action and the DRR agenda at various levels where their presence is required and valued and their contribution is distinctively acknowledged, NGOs have been an integral part of the global disaster risk reduction (DRR) ecosystem (Benson et al., 2001). Here, we can see that all people benefit from the awareness programs of NGOs. According to the participants, these awareness programs mainly help to inform the victims about the time and frequency of the flood. Almost 53% of people get economic support to manage flood impacts, 44.67% get relief support, but amazingly, 55.33% of people are deprived of such assistance. NGOs and others conducting evacuation programs support 15.33% of respondents (Figure 5). Different NGOs are successfully trying to reduce the flood risk and improve the socio-economic life of the victims. Providing easy loans is a common practice among NGOs. It has also been claimed by the respondents that the loan interest is relatively higher than their standard. Helena Banu said, " *I borrowed 20000 tk from a local NGO 2 years ago at a higher interest, and I have to go through huge hardship to return the loan.*"

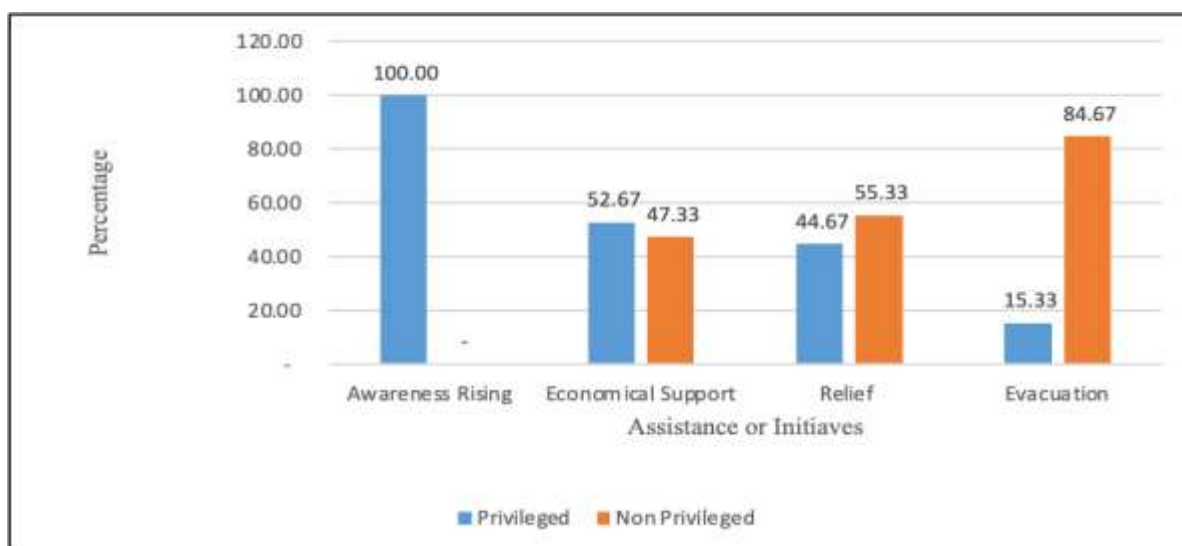


Figure 5: Initiatives or assistance from NGOs and other sources to manage flood impacts (Source: Field Survey-2020)

4.10 Further needs for proper flood management: Although complete prevention of floods is unattainable, their adverse consequences can be significantly mitigated through strategic preparation and diligent planning (Aslam 2018). The knowledge gap is clearly reflected when people talk about flood management; they only talk about structural development, whereas non-structural measures are equally important for risk reduction. The respondents demanded different structural developments like flood shelters, embankments, and floodproofing techniques. When asked about better employment facilities, many agreed that better job facilities can reduce their misery. We can see that all people agreed that they require school cum flood shelters and sustainable embankments to manage flood impacts which are needs that should be added to existing assistance or initiatives for proper flood management. Here, we can also see that 70% of people ask for employment opportunities, and 56.67% demand floodproofing to manage flood impacts (Table 2). During the field survey, it was seen that the public infrastructure, especially schools, does not have high basements to counter floodwater. So, school cum flood shelters will be multipurpose projects, and the effectiveness will also increase a lot. Building of embankments on the riverside is a common demand of the villagers. Many areas of Udaykhali and Kanchipara have already been taken under embankment facilities and in many areas, the embankment construction is ongoing. Regarding the profession, the study area is dominated by farmers; nearly 65% of the respondents are farmers here (Table 1). Farmers become unemployed during the monsoon. To keep the people earnable, the cottage industry can be introduced here. In that case, subsidies, interest-free loans and proper training programs should be launched by the government and NGOs. Identifying susceptible flood zones can be an effective initiative that can help inhabitants to build their houses in safer places. Accurately predicting the length and severity of floods can also help farmers with crop production.

Table 2: Needs should be added based on public demands to manage the flood impacts.

Needs	Agreed (n)	Response in Percentage
School cum flood shelter	150	100.00
Sustainable Embankment	150	100.00
Employment Opportunity	105	70.00
Flood Proofing	85	56.67

4.11 Knowledge of flood preparedness and post-flood recovery techniques: Flood preparedness among the victims is about construction and reconstruction (Ridzuan et al., 2024). It is important to keep social and economic life sustainable after flood recovery. Though most of the participants (82%) (Figure 6) claimed that they possessed knowledge about post-flood recovery close observation revealed that they actually lacked well-structured and detailed knowledge about post-flood recovery. Some of the respondents who identified as knowledgeable had a general understanding of home and infrastructure recovery but lacked an organized comprehension of the aspects of social, economic, physical, and institutional recovery that contribute to a community's resilience to floods.

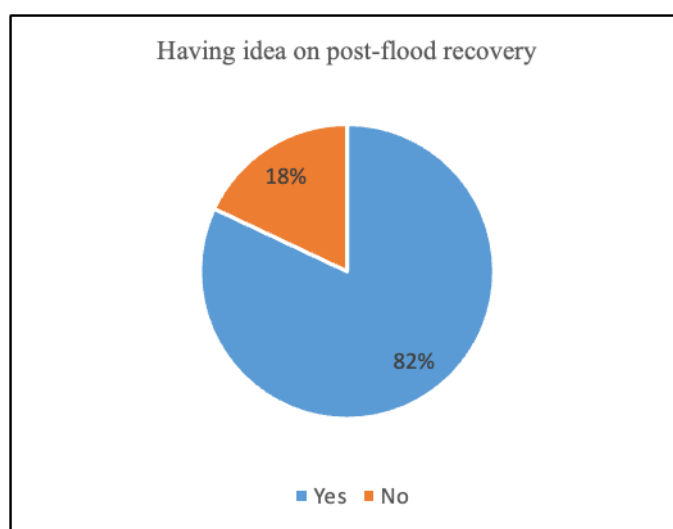


Figure 6: Knowing post-flood recovery (Source: Field Survey-2020)

4.12 The knowledge gaps in post-flood recovery: During the post-flood recovery stage, there is a chance to create and execute strategies to reduce risk through recovery programs and awareness initiatives. In the interest of both economic prudence and the capacity of societies to learn, analysis of post-disaster recovery processes via medium- and long-term feedback enables confirmation, beyond the time, stakeholders, and territory diagnosis phase, that the reconstruction phase should be regarded as a preventive opportunity (Moatty, 2017). We have marked some criteria in the form of knowledge gaps to get insight into the existing knowledge of the targeted population. Some options, including 'Absence of standard policy', 'Lack of public awareness', and 'Inferiority in collaboration', were presented to the respondents so that they could identify the actual gap of knowledge in their disaster resiliency. The data reflected that 78% of respondents identified the 'Absence of standard policy' as a reason behind the knowledge gap. 'Lack of public awareness' is the major reason behind this gap, supported by 86% of respondents, while almost 49% said 'Inferiority in collaboration' among the public and policymakers is also responsible for this gap. Almost 26% of the three reasons are responsible for knowledge gaps in the study area (Figure 7). Bangladesh's current flood regulatory framework is primarily effective in providing aid and response during flooding. However, it exhibits notable deficiencies and insufficient provisions to enhance communities' adaptive capacity and resilience in confronting forthcoming flooding vulnerabilities induced by climate change. To close the information gap on flood recovery, the authority should implement a uniform policy integrating flood resilience, post-flood recovery, and pre-flood planning. Insufficient awareness contributes to low motivation to engage in DDR

programs (Fekete et al., 2021). Though it has been claimed by the local authority that awareness programs are organized regularly, in the people's perception, the awareness programs are not that effective for them. It is worth mentioning that NGOs often launch awareness programs, but public participation in those programs is very low. Khairul Islam, a field officer of a renowned NGO (BRAC), said, "We routinely organize training and awareness programs, but participation is lowering day by day. At the last meeting, only 6 women attended, whereas the expected participants were 70." This happens as people treat these programs as a waste of time. A significant number of the participants share the objection that the local governing body frequently disregards their views, which is a contributing factor to their increased distress. Therefore, it is our contention that training programs ought to be organized for local governing bodies and that their operations ought to be strictly monitored.

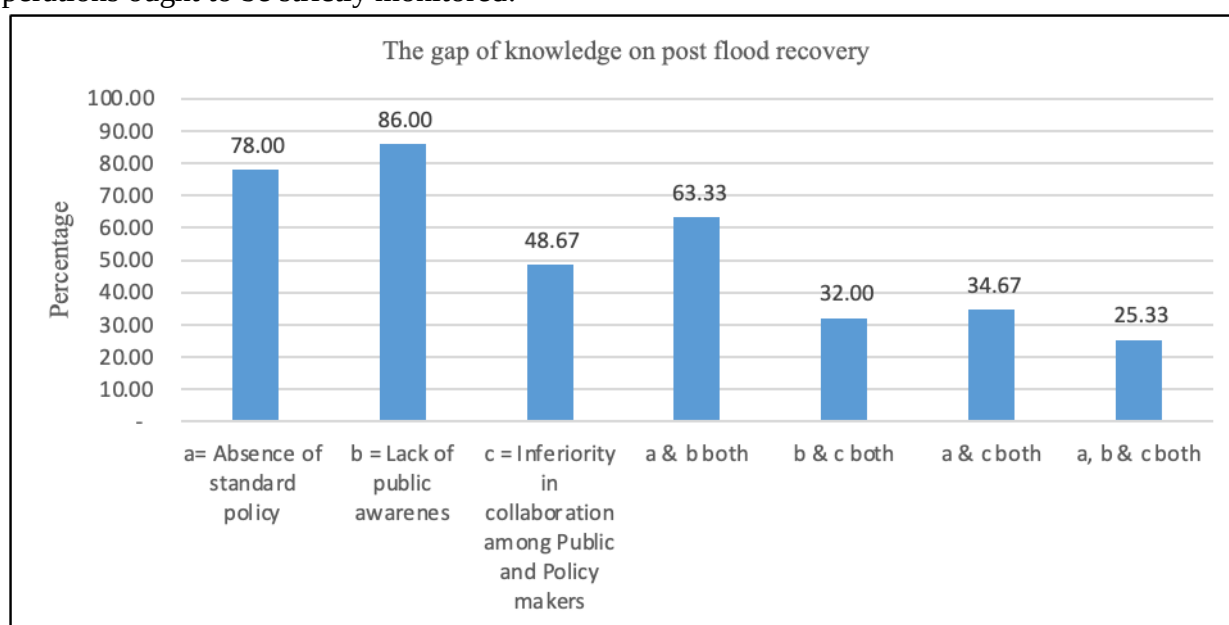


Figure 7: Knowledge gaps status on post-flood recovery at Fulchhari Upazila (Data: Field Survey-2020).

4.13 Needs and difficulties for recovery: Needs for flood recovery vary from community to community and area to area (Kotani et al., 2023). Restrictive identification criteria, lengthy application processes, and eligibility restrictions tied to absolute economic loss are common variables that contribute to disadvantaged people's unequal access to rehabilitation programs (Wilson et al., 2021). It seemed that the studied population has some very specific demands through which they believe the disaster risk can be reduced. All of the respondents said that the aforementioned recoveries don't have completeness, and they suggested various elements that are needed for proper recovery. Table 4 shows that all of the flood victims have a demand for sustainable shelters, 84% have a demand for river excavation as flood preparedness, and almost 65% need collaboration among government and NGOs, where 23% of respondents asked for a bottom-up management system for proper flood management. Almost all respondents said that the government and NGOs are not playing a role in rebuilding elements in time and on a proper scale. There are many difficulties behind this scenario. About 70% of people mention nepotism as a difficulty, and 60% think the imbalanced distribution of relief and support is another difficulty whereas almost 57% acknowledge the lack of collaboration (Table 3). During an FGD most of the participants complained that the breaches of the embankments were not repaired in time. Local people themselves have to take steps with local materials to rebuild and reconstruct the

embankments, which are often ineffective. Jasim Sheikh, a 40 years-old small businessman, stated, " I, along with my two brothers, have spent 60000 taka to repair the breach of the embankment near my house. Local authorities rarely pay heed to our urges." Lack of funding is one of the significant reasons behind the halting of the development processes. Without disclosing their name, one of the officials of the local governing body said, " I agree with the fact that some of the development process is delayed, and it is also true that we cannot help all the affected people. We do not get enough funds to satisfy all the victims. Moreover, the number of executives in the local governing body is also low. We have to struggle to distribute and manage the relief goods during the emergency as the activist's number is minimal". Only the local governing body cannot be blamed for not fulfilling the recovery needs. Proper funding should be issued, and the local community should help the local authority by providing accurate information about the victims.

Table 3: Elements needed for proper recovery.

Sl. No.	Elements for proper recovery	n	%
01	Sustainable Shelter	150	100.00
02	River Excavation	126	84.00
03	Collaboration among Govt. and NGOs	97	64.67
04	Bottom-up Management System	35	23.33

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Table 4: Difficulties in proper recovery.

Sl. No.	Difficulties	n	%
01	Nepotism	105	70.00
02	Imbalanced Distribution	90	60.00
03	Lack of Collaboration	85	56.67

5. Conclusions and Recommendations:

The study was conducted to identify flood hazards, their impacts, and the post-recovery status in Fulchhari Upazila, Gaibandha. Riverine floods are the most devastating natural disasters in northern Bangladesh, and Fulchhari Upazila is particularly vulnerable to frequent flooding. The geographic location of this Upazila significantly contributes to its flood susceptibility. Analysis of field survey data reveals that the area experiences river floods and their annual impacts. To manage these flood impacts, nearly 45% of households seek shelter on rafts or boats. Most respondents reported that flood impacts are severe across various sectors, including health, agriculture, livestock, education, embankments, and road communications. The overall survey in the study area reveals that many people are particularly concerned about agricultural damage, as this sector is most affected by floods compared to other hazards. Although some flood management actions have been undertaken by the government and NGOs, basic post-flood recovery efforts in Fulchhari

remain neglected. Among informed respondents, some are only aware of household and infrastructure recovery, lacking knowledge about embankment, transportation, communication, and other essential recovery elements needed to make a community more resilient to floods. About 18% of respondents lack basic knowledge of post-flood recovery concepts. Notably, 78% of respondents attribute this knowledge gap to the absence of a standard policy. Lack of public awareness is considered a major reason for this gap, supported by 86% of respondents, while nearly 49% cite poor collaboration between the public and policymakers as a contributing factor. Approximately 26% believe that the combination of these three reasons is responsible for the knowledge gaps in the study area. In Fulchhari, all respondents, who are aware of post-flood recovery believe that proper recovery from flood damage is a form of future flood preparedness. Among them, 54% report river excavation as a recovery option that reduces the impact of future floods, and 46% believe that sustainable embankments reduce the probability and impacts of future floods. In association with proper recovery, awareness-raising programs, training programs, volunteer involvement, and enhancing the management system, proper education should be emphasized to build a resilient community. Although it is not possible to prevent the occurrence of floods, a proper plan, preparedness, adaptation techniques, management, human collective participation, post-damage assessment, and recovery can minimize the impacts of floods and enhance community resilience.

By using the results of this research, policymakers and planners can establish a foundation for predicting flood risk, mitigating damages and casualties, and facilitating the recovery process for individuals impacted by flooding. Based on overall observations, discussion, analyses, and conclusions, the following recommendations are made for better post-recovery flood risk management initiatives and to reduce the future impacts of floods to enhance the resiliency of the flood-affected community:

- Elementary flood damage and loss assessment are required for proper post-recovery.
- Post-recovery of infrastructure, embankment, transportation, communication, and other sectors should be considered as future flood preparedness.
- The construction and management of school-cum-flood shelters should be enhanced.
- Government and non-governmental organizations should take actions to provide alternative job opportunities to aid in recovery from losses.
- Raising the bases of tube wells and sanitary toilets is necessary to secure safe drinking water.
- Government and key stakeholders should engage communities and local authorities in increasing awareness of the flood risk given climate variability.
- Awareness-raising programs, training, early warning systems, and consciousness of proper recovery and preparedness for future floods should be considered in policy planning.
- Flood zoning can be implemented to mark the most susceptible areas.
- Local governing bodies should receive proper training.

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Knowledge and Practices Regarding Antibiotic Use Among Bio-Science and Non-Bio-Science Students at Barishal University

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Abstract

Improper antibiotic use is an important contributor to antimicrobial resistance, an increasing global public health concern. This cross-sectional study assessed antibiotic-related knowledge and practices among university students at the University of Barishal, Bangladesh. Using an online questionnaire and purposive sampling, 380 students participated. The questionnaire included eight antibiotic-related knowledge and five practice items, with the latter used to construct a composite practice score. Descriptive statistics, bivariate analysis, and ordinal logistic regression were used to examine these outcomes and their associated factors. Most participants (93.4%) correctly recognized that antibiotics are effective against bacterial infections, but 65.8% incorrectly believed they are also effective against viral infections. Self-medication was reported by 51.1%, while 52.4% did not complete their prescribed antibiotic course. Non-bio-science students (OR = 0.4, 95% CI: 0.2–0.6, $p < 0.001$) and those who practiced self-medication (OR = 0.1, 95% CI: 0.0–0.2, $p < 0.001$) had lower odds of reporting higher self-rated knowledge. Self-rated knowledge was significantly associated with antibiotic use practices ($p < 0.05$), whereas gender, age, academic status, and faculty were not. Despite generally good recognition that antibiotics are effective against bacterial infections, misconceptions and suboptimal practices were observed, highlighting the need for targeted educational interventions to promote appropriate antibiotic use and stewardship.

Keywords: Antimicrobial resistance, knowledge, practices, self-medication, university students, Bangladesh

Introduction

Antibiotics represent one of the greatest advances in modern medicine, having saved millions of lives worldwide through the effective treatment of bacterial infections. However, antimicrobial resistance (AMR), now recognized as a major global public health challenge, has been accelerated by inappropriate antibiotic use (Murray et al., 2022; World Health Organization, 2025). AMR occurs when microorganisms, particularly bacteria, develop mechanisms that reduce their susceptibility to previously effective antibiotics (Azim et al., 2023). Consequently, infections become more difficult to treat, potentially increasing mortality, prolonging illness, and raising healthcare costs. Recent estimates suggest that, if current trends continue, AMR could directly contribute to more than 39 million deaths between 2025 and 2050 (Naghavi et al., 2024). Although AMR is a global concern, its drivers vary across healthcare systems and socioeconomic contexts. In low- and middle-income countries such as Bangladesh, factors including non-prescription access to antibiotics, limited awareness regarding appropriate use, and self-medication practices may contribute to the growing burden of AMR (Raihan et al., 2024; Sarker et al., 2026).

Recent evidence from Bangladesh suggests that more than half of available antibiotics belong to the World Health Organization's Watch category, highlighting the need for careful monitoring of their

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use to reduce resistance development (Rani et al., 2024). Despite these concerns, misconceptions and inappropriate antibiotic use behaviors remain common among university students. Although students from medical and health-related disciplines generally demonstrate greater antibiotic knowledge than those from other academic backgrounds, inappropriate practices have also been reported among these groups (Bonna et al., 2024; Siam et al., 2021). For example, previous studies among Bangladeshi university students found high levels of antibiotic self-medication and incomplete adherence to prescribed antibiotic courses (Paul et al., 2022). Similar patterns, including non-prescription antibiotic use and misconceptions regarding antibiotic effectiveness against viral illnesses, have also been reported during the COVID-19 pandemic and among residential university students in Bangladesh (Islam et al., 2021; Wahab et al., 2023).

Previous studies have suggested that academic background may be associated with antibiotic-related knowledge and practices. Students from biology, medicine, and other health-related disciplines often demonstrate greater awareness of antibiotic use and AMR compared with students from non-health fields (Dyar et al., 2018). However, higher knowledge does not always correspond to appropriate antibiotic use behaviors, as inappropriate practices such as self-medication, early discontinuation of treatment, and non-prescription purchasing have also been reported among knowledgeable student groups (Paul et al., 2022; Wahab et al., 2023). Similar observations have been reported internationally, where health-related students showed greater antibiotic awareness but continued to engage in inappropriate practices (Hu et al., 2018; Precha et al., 2024; Suaifan et al., 2012). These findings suggest that inappropriate antibiotic use among university students represents a broader public health concern extending beyond individual countries.

Nevertheless, important gaps remain in the Bangladeshi literature. Many previous studies have focused on self-medication, general awareness, or antibiotic knowledge among university students, often within single institutions (Paul et al., 2022). Although some studies have compared students from biological and non-biological backgrounds (Marzan et al., 2021), evidence from public universities in regional areas of Bangladesh remains limited. Furthermore, relatively few studies have used multivariable ordinal logistic regression to examine factors associated with antibiotic-related knowledge and practices. Therefore, the relationship between demographic characteristics, knowledge levels, and antibiotic use practices remains insufficiently explored within a unified analytical framework.

The present study was conducted at the University of Barishal, a public university in southern Bangladesh that includes students from both bio and non-bio science faculties. The presence of these distinct academic groups provides an opportunity to examine differences in antibiotic-related knowledge and practices across educational backgrounds. Accordingly, the study aimed to provide additional evidence by (i) evaluating and comparing antibiotic-related knowledge and practices among students from these academic groups and (ii) examining demographic and behavioral factors associated with both outcomes using ordinal logistic regression. The findings may contribute to a better understanding of antibiotic-related knowledge and practices among university students and provide evidence to inform future educational interventions and antimicrobial stewardship strategies in Bangladesh.

Materials and Methods

Study Design and Setting

The present cross-sectional study was conducted among students at the University of Barishal, Bangladesh. Primary data were collected using a structured, self-administered online questionnaire distributed via email.

Questionnaire Development and Data Collection

The questionnaire was developed by the authors after reviewing relevant previous studies on antibiotic-related knowledge and antibiotic use practices and was refined under the guidance of the study supervisor. Before the main survey, the questionnaire was pretested among a small group of students to assess its comprehensibility, clarity, language, and relevance to the study objectives. Necessary revisions were made based on the feedback received during the pretesting process. The final questionnaire comprised nineteen items covering participants' demographic characteristics, self-rated knowledge, antibiotic-related knowledge, and antibiotic use practices, including eight antibiotic-related knowledge items and five practice items. The questionnaire was developed specifically for this study, and its face and content validity were reviewed through expert evaluation and pretesting before data collection.

Sampling Technique and Study Participants

Students enrolled in Bachelor of Science (Honours) and Master of Science programs from both bio and non-bio science faculties were invited to participate in the online survey. Purposive sampling was adopted because the primary objective of the study was to compare students from these two academic backgrounds. A total of 380 students completed the survey and were included in the analysis. Participants were categorized into three age groups: 18–20 years, 21–23 years, and older than 23 years.

Variable Measurement

For the knowledge model, the dependent variable was participants' self-rated knowledge of antibiotic use, categorized as Poor, Moderate, or Good. Independent variables included gender, age, academic status, faculty, frequency of self-medication, usual method of obtaining antibiotics, and previous experience with antibiotic resistance.

For the practice model, the dependent variable was the composite antibiotic use practice level, categorized as Low-risk, Medium-risk, or High-risk. The composite practice index was constructed using the five practice-related items to assess antibiotic use behavior. During data processing in R, each response category was assigned an ordinal numerical score reflecting the appropriateness of the reported behavior, with higher scores indicating less appropriate and potentially greater risk of inappropriate antibiotic use. Individual item scores were summed to obtain the composite practice score, which was then normalized by dividing by the maximum possible score (9). Based on the normalized scores, participants were classified into three ordered categories: Low-risk (< 0.33), Medium-risk ($0.33\text{--}0.66$), and High-risk (> 0.66) antibiotic use practices. Independent variables included gender, age, academic status, faculty, and self-rated knowledge of antibiotic use. Consequently, higher practice categories represented progressively greater risk of inappropriate antibiotic use.

Statistical Analysis

Frequency distributions were generated for all questionnaire items, and descriptive statistics were calculated for all study variables. Bivariate cross-tabulations were used to examine the distribution of antibiotic use practice categories across participant characteristics. To investigate factors associated with antibiotic-related knowledge and antibiotic use practices, separate ordinal logistic regression models were fitted for the two ordinal outcome variables. Ordinal logistic regression was selected because both outcome variables consisted of naturally ordered categories. Basic diagnostic procedures available in R were performed to assess overall model adequacy before interpreting the regression results. Odds ratios (ORs) with 95% confidence intervals (CIs) and corresponding p-values are reported. A two-sided p-value < 0.05 was considered statistically significant.

Results and Discussion

The study participants' knowledge and practices regarding antibiotic use are summarized in Table 1. Overall, although 93.4% of students correctly identified that antibiotics are effective against bacterial infections, 65.8% incorrectly believed that they are also effective against viral infections. These findings suggest that misconceptions regarding the appropriate use of antibiotics were common despite generally good awareness of their role in treating bacterial infections.

Table 1. Descriptive summary of key study variables

Variable	Frequency (n)	Percentage (%)
Belief: Antibiotics are effective for bacterial infections		
Correct	355	93.4
Wrong	25	6.6
Belief: Antibiotics are effective for viral infections		
Correct	130	34.2
Wrong	250	65.8
Self-rated knowledge on antibiotics		
Good	30	7.9
Moderate	284	74.7
Poor	66	17.4
Self-medication		
No	30	7.9
Sometimes	156	41.1
Yes	194	51.1
Usual method of obtaining antibiotics		
Physician's prescription	89	23.4
Self-medication	124	32.6
Suggested by pharmacists	123	32.4
Suggested by friends/relatives	41	10.8
Other*	3	0.8
Usual timing for starting antibiotics		
For fever	177	46.6
For any kind of pain	100	26.3
For a cough or cold	86	22.6
For urinary infection	12	3.2
Other†	5	1.3

Antibiotic use in the past six months		
No	45	11.8
Yes	335	88.2
Completion of prescribed antibiotic course		
No	199	52.4
Yes	181	47.6
Reason for incomplete antibiotic course		
Forgot to take medicine properly	189	49.7
Stopped after feeling better	67	17.6
Stopped due to allergic reaction	59	15.5
Stopped due to stomach discomfort	59	15.5
Other†	6	1.6
Experience with antibiotic resistance		
No	224	58.9
Yes	156	41.1
Antibiotic practice level		
Low-risk	19	5.0
Medium-risk	234	61.6
High-risk	127	33.4

Note: Other* includes respondents who usually used antibiotics according to a previous prescription (n = 3). Other† includes bacterial pneumonia, bloodstream infections, skin abscess, antibiotics only when prescribed by a physician, and respondents reporting no antibiotic use (total n = 5). Other‡ includes "No antibiotics in the last six months" and "No specific reason" (total n = 6).

Similar misconceptions have been reported among Malaysian university students, suggesting that such misunderstandings may occur across different educational settings (Tiong & Chua, 2020). Regarding the frequency of self-medication, 51.1% of participants reported that they practiced self-medication, while only 23.4% usually obtained antibiotics through a physician's prescription. Most participants rated their antibiotic knowledge as moderate (74.7%), whereas only 7.9% rated it as good. Although 88.2% of participants had used antibiotics during the previous six months, only 47.6% completed their prescribed course of treatment. A reason category was assigned to all 380 respondents, with forgetting to take the medication being the most frequently reported category (49.7%), followed by stopping treatment after feeling better (17.6%). Furthermore, 46.6% reported usually starting antibiotics for fever and 26.3% for any kind of pain, which may reflect inappropriate antibiotic use practices. These findings are broadly consistent with previous studies reporting self-medication and suboptimal adherence to antibiotic therapy among university students, suggesting that knowledge alone may not always translate into appropriate antibiotic use practices (Marzan et al., 2021; Tiong & Chua, 2020). This observation is further supported by a systematic review reporting a pooled self-medication prevalence of 46.0% among university students in low- and middle-income countries (Xu et al., 2019).

Table 2 presents the distribution of antibiotic use practice levels according to participant characteristics. Higher proportions of high-risk practices were observed among students who reported practicing self-medication (48.5%) compared with those who practiced self-medication sometimes (20.5%) or did not practice self-medication (3.3%). Similarly, compared with students who usually obtained antibiotics through a physician's prescription (16.9%), those who relied on self-medication (37.9%) or recommendations from friends or relatives (48.8%) had higher proportions of high-risk practices. Participants who took antibiotics for any kind of pain also showed a substantially

higher proportion of high-risk practices (63.0%) than those who took antibiotics for fever (12.4%). Differences across demographic characteristics were comparatively modest. The proportion of high-risk practices was higher among students aged 21–23 years (37.8%), undergraduates (37.5%), and non-bio-science students (35.3%) than among their respective comparison groups. Likewise, students reporting good self-rated knowledge had a lower proportion of high-risk practices (20.0%) than those reporting moderate (34.5%) or poor (34.8%) self-rated knowledge. These patterns are broadly consistent with previous Bangladeshi studies reporting substantial antibiotic self-medication among university students and the use of antibiotics for conditions such as fever (Wahab et al., 2023). However, because these findings are descriptive, they should be interpreted cautiously, as they do not account for potential confounding factors. The independent associations were therefore examined using ordinal logistic regression.

Table 2. Distribution of antibiotic use practice levels according to participant characteristics

Variable	Low-risk, n (%)	Medium-risk, n (%)	High-risk, n (%)
Gender			
Female	9 (6.6)	78 (56.9)	50 (36.5)
Male	10 (4.1)	156 (64.2)	77 (31.7)
Age (years)			
>23	9 (7.8)	76 (66.1)	30 (26.1)
18–20	3 (8.6)	22 (62.9)	10 (28.6)
21–23	7 (3.0)	136 (59.1)	87 (37.8)
Academic status			
Master's	7 (4.7)	101 (68.2)	40 (27.0)
Undergraduate	12 (5.2)	133 (57.3)	87 (37.5)
Faculty			
Bio-science	10 (4.1)	155 (63.5)	79 (32.4)
Non-bio-science	9 (6.6)	79 (58.1)	48 (35.3)
Self-rated knowledge on antibiotics			
Good	5 (16.7)	19 (63.3)	6 (20.0)
Moderate	11 (3.9)	175 (61.6)	98 (34.5)
Poor	3 (4.5)	40 (60.6)	23 (34.8)
Self-medication			
No	13 (43.3)	16 (53.3)	1 (3.3)
Sometimes	5 (3.2)	119 (76.3)	32 (20.5)
Yes	1 (0.5)	99 (51.0)	94 (48.5)
Usual method of obtaining antibiotics			
Previous prescription	2 (66.7)	0 (0.0)	1 (33.3)
Physician's prescription	10 (11.2)	64 (71.9)	15 (16.9)
Self-medication	2 (1.6)	75 (60.4)	47 (37.9)
Suggested by friends or relatives	1 (2.4)	20 (48.8)	20 (48.8)
Suggested by pharmacists	4 (3.3)	75 (61.0)	44 (35.8)
Usual timing for starting antibiotics			

Variable	Low-risk, n (%)	Medium-risk, n (%)	High-risk, n (%)
Fever	9 (5.1)	146 (82.5)	22 (12.4)
Any kind of pain	0 (0.0)	37 (37.0)	63 (63.0)
Cough or cold	1 (1.2)	43 (50.0)	42 (48.8)
Urine infection	6 (50.0)	6 (50.0)	0 (0.0)
Other†	3 (60.0)	2 (40.0)	0 (0.0)
Antibiotic use in the past six months			
No	13 (28.9)	24 (53.3)	8 (17.8)
Yes	6 (1.8)	210 (62.7)	119 (35.5)
Completion of prescribed antibiotic course			
No	11 (5.5)	144 (72.4)	44 (22.1)
Yes	8 (4.4)	90 (49.7)	83 (45.9)
Reason for incomplete antibiotic course			
Forgot to take medicine properly	8 (4.2)	122 (64.6)	59 (31.2)
Stopped due to allergic reaction	3 (5.1)	33 (55.9)	23 (39.0)
Stopped after feeling better	6 (9.0)	42 (62.7)	19 (28.4)
Stopped due to stomach discomfort	1 (1.7)	34 (57.6)	24 (40.7)
Other‡	1 (16.7)	3 (50.0)	2 (33.3)
Experience with antibiotic resistance			
No	17 (7.6)	169 (75.4)	38 (17.0)
Yes	2 (1.3)	65 (41.7)	89 (57.1)

Note: Other† includes bacterial pneumonia (n = 1), bloodstream infection (n = 1), skin abscess (n = 1), no antibiotic use (n = 1), and antibiotics taken only when prescribed by a physician (n = 1). Other‡ includes no antibiotics in the previous six months (n = 1) and no specific reason (n = 5; combining equivalent “no reason” responses).

The ordinal logistic regression analysis of factors associated with students' self-rated antibiotic knowledge is presented in Table 3. The overall model was statistically significant (Likelihood Ratio, $\chi^2 = 41.4$, $p < 0.001$), indicating a significantly better fit than the intercept-only model in explaining variation in self-rated knowledge. Among the explanatory variables, faculty and self-medication behavior were significantly associated with the outcome. Compared with students from bio-science faculties, those from non-bio-science faculties had lower odds of reporting higher self-rated knowledge (OR = 0.4, 95% CI: 0.2–0.6, $p < 0.001$). A similar finding was reported in Jordan, where medical students demonstrated significantly higher knowledge than non-medical students ($p < 0.001$) (Suaifan et al., 2012). Likewise, compared with students who did not practice self-medication, those who reported sometimes practicing self-medication (OR = 0.1, 95% CI: 0.0–0.3, $p < 0.001$) and those who reported practicing self-medication (OR = 0.1, 95% CI: 0.0–0.2, $p < 0.001$) had lower odds of reporting higher self-rated knowledge. Gender, age, academic status, previous experience with antibiotic resistance, and the usual method of obtaining antibiotics were not significantly associated with self-rated knowledge ($p \geq 0.1$). These findings are also consistent with previous evidence from Bangladesh reporting an association between greater antibiotic knowledge and more appropriate

antibiotic selection behavior among university students ($p = 0.017$) (Paul et al., 2022), suggesting that greater antibiotic knowledge may be associated with more appropriate antibiotic use behaviors.

Table 3. Ordinal logistic regression of factors associated with self-rated antibiotic knowledge

Variable	Odds Ratio (OR)	95% Confidence Interval (LL–UL)	p-value
Gender			
Female (<i>ref</i>)	1.0	—	—
Male	0.6	0.3–1.0	$p \geq 0.1$
Age (years)			
(<i>ref</i>)	1.0	—	—
18–20	1.8	0.6–4.9	$p \geq 0.1$
21–23	1.2	0.7–2.2	$p \geq 0.1$
Academic status			
Master's (<i>ref</i>)	1.0	—	—
Undergraduate	0.8	0.5–1.4	$p \geq 0.1$
Faculty			
Bio-science (<i>ref</i>)	1.0	—	—
Non-bio-science	0.4	0.2–0.6	$p < 0.001$
Self-medication			
No (<i>ref</i>)	1.0	—	—
Sometimes	0.1	0.0–0.3	$p < 0.001$
Yes	0.1	0.0–0.2	$p < 0.001$
Experience with antibiotic resistance			
No (<i>ref</i>)	1.0	—	—
Yes	1.0	0.6–1.7	$p \geq 0.1$
Usual method of obtaining antibiotics			
Previous prescription (<i>ref</i>)	1.0	—	—
Physician's prescription	0.6	0.0–14.1	$p \geq 0.1$
Self-medication	0.6	0.0–14.8	$p \geq 0.1$
Suggested by friends/relatives	1.9	0.1–47.0	$p \geq 0.1$
Suggested by pharmacists	0.9	0.0–21.6	$p \geq 0.1$
Model thresholds			
Poor Moderate	0.0	0.0–0.2	$p < 0.01$
Moderate Good	0.7	0.0–17.0	$p \geq 0.1$

Note: The abbreviations LL and UL denote the Lower Limit and Upper Limit of the 95% confidence interval, respectively, and "*ref*" indicates the reference category.

The ordinal logistic regression analysis of factors associated with antibiotic use practice is summarized in Table 4. The overall regression model was statistically significant (Likelihood Ratio $\chi^2 = 14.6$, $p = 0.042$), indicating that it provided a significantly better fit than the intercept-only model. Self-rated knowledge was the only variable significantly associated with antibiotic use practice. Compared with students who rated their antibiotic knowledge as good, those reporting moderate knowledge (OR = 3.0, 95% CI: 1.3–7.3, $p < 0.05$) and poor knowledge (OR = 2.9, 95% CI: 1.1–7.9, $p < 0.05$) had significantly higher odds of belonging to a higher antibiotic use practice

category. Because higher practice categories represent progressively higher-risk antibiotic use behaviors, these findings indicate that students with moderate or poor self-rated knowledge were more likely to report riskier antibiotic use practices than those with good self-rated knowledge. Gender, age, academic status, and faculty were not significantly associated with antibiotic use practice after adjustment for the other variables ($p \geq 0.1$). Because knowledge was self-rated rather than objectively assessed, this association should be interpreted cautiously and not as evidence of causality. Previous evidence also suggests that greater antibiotic knowledge may not necessarily translate into appropriate antibiotic use practices (Paul et al., 2022), indicating that factors beyond knowledge may also contribute to antibiotic use behavior.

Taken together, these findings suggest that self-rated antibiotic knowledge may be associated with antibiotic use practices, although other factors may also contribute to variations in such behaviors. Further studies using validated objective knowledge assessments are needed to better understand this observed association.

Table 4. Ordinal logistic regression of factors associated with antibiotic use practices

Variable	Odds Ratio (OR)	95% Confidence Interval (LL–UL)	p-value
Gender			
Female (<i>ref</i>)	1.0	—	—
Male	0.7	0.5–1.2	$p \geq 0.1$
Age (years)			
>23 (<i>ref</i>)	1.0	—	—
18–20	1.0	0.4–2.4	$p \geq 0.1$
21–23	1.6	1.0–2.7	$p \geq 0.1$
Academic status			
Undergraduate (<i>ref</i>)	1.0	—	—
Master's	1.2	0.8–2.0	$p \geq 0.1$
Faculty			
Bio-science (<i>ref</i>)	1.0	—	—
Non-bio-science	1.0	0.6–1.6	$p \geq 0.1$
Self-rated knowledge			
Good (<i>ref</i>)	1.0	—	—
Moderate	3.0	1.3–7.3	$p < 0.05$
Poor	2.9	1.1–7.9	$p < 0.05$
Model thresholds			
Low Medium	0.2	0.1–0.4	$p < 0.001$
Medium High	7.3	2.8–19.0	$p < 0.001$

Note: The abbreviations LL and UL denote the Lower Limit and Upper Limit of the 95% confidence interval, respectively, and "*ref*" indicates the reference category.

According to Fig. 1, 79.2% of the 380 students at the University of Barishal were aware that antibiotic resistance can occur due to antibiotic overuse or missed doses, while 76.1% understood that antibiotic resistance may lead to loss of antibiotic effectiveness. However, 25.0% of respondents believed that antibiotics were effective for both bacterial and viral infections, and 36.8% considered antibiotics effective for fever or allergies. This misconception is consistent with findings from Malaysia, where a substantial proportion of university students also reported similar beliefs about antibiotic use for viral illnesses (Tiong & Chua, 2020). Although 68.4% of students understood that antibiotics should

not be discontinued when symptoms subside, 41.3% reported using antibiotics without a prescription. Students who reported completing their prescribed antibiotic course had a higher proportion of high-risk practices (45.9%) than those who did not (22.1%). This pattern suggests an association between antibiotic course completion and antibiotic use practice levels. These findings provide additional context to previous Bangladeshi studies, which mainly focused on the prevalence of self-medication rather than the association between antibiotic course completion and antibiotic use practices (Paul *et al.*, 2022).

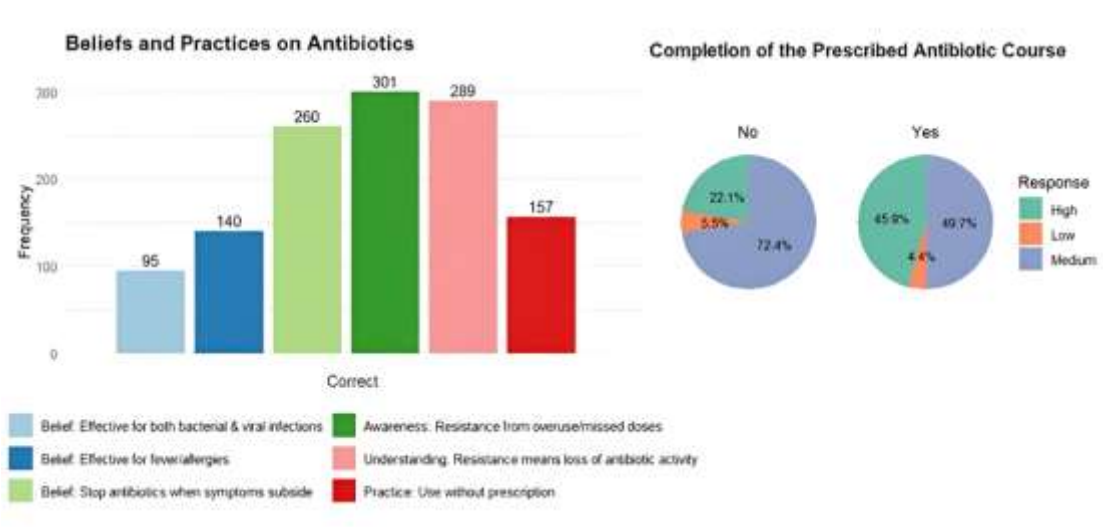


Fig 1. Distribution of beliefs, awareness, and practices related to antibiotic use

Fig 2 illustrates the distribution of respondents according to selected demographic and academic characteristics. Males constituted a larger proportion of the participants than females (63.9% vs. 36.1%). Most participants were aged 21–23 years (60.5%), followed by those aged above 23 years (30.3%) and those aged 18–20 years (9.2%). Undergraduate students accounted for 61.1% of the participants, while master's students accounted for 38.9%. Similarly, bio-science students comprised 64.2% of the sample, compared with 35.8% from non-bio-science faculties.

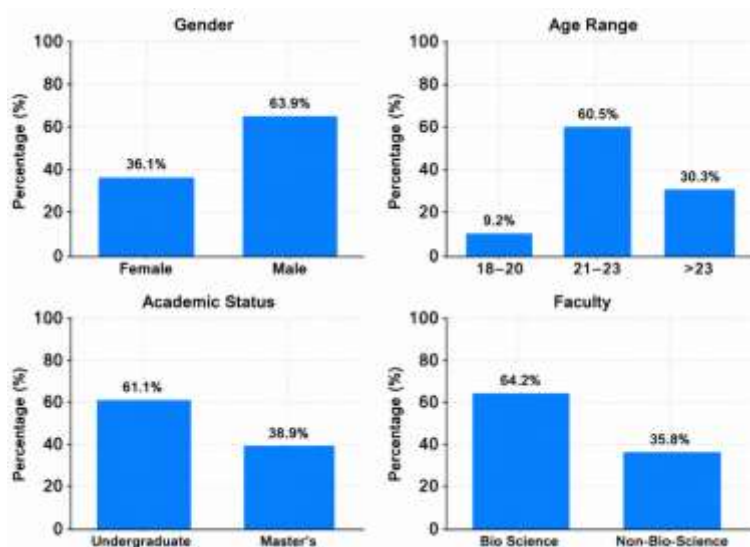


Fig 2. Distribution of respondents by demographic and academic characteristics

Limitations

This study has several limitations. First, its cross-sectional design precludes establishing temporal relationships or causal inferences. Second, the study was conducted at a single public university using purposive sampling and email-based data collection, which may have introduced selection bias and may limit the generalizability of the findings. Furthermore, antibiotic use practices and knowledge were self-reported, which may have introduced recall and social desirability biases. In addition, antibiotic knowledge was assessed based on participants' self-ratings rather than objective measures, which may have resulted in misclassification of perceived knowledge. Some potentially important factors, including socioeconomic status, previous health education, and access to healthcare services, were not examined and may have contributed to the observed associations. Moreover, comprehensive psychometric evaluation of the questionnaire beyond face and content validity assessment, as well as detailed model diagnostic assessments, was beyond the scope of this study. Future research incorporating larger multi-institutional samples, probability-based sampling, validated objective knowledge measures, comprehensive questionnaire validation, and more extensive model diagnostics may help confirm and extend these findings.

Conclusion

This study examined antibiotic-related knowledge and practices among students at the University of Barishal and identified important gaps in antibiotic-related knowledge and use practices. Although most participants correctly recognized that antibiotics are effective against bacterial infections, misconceptions regarding their use for viral infections were observed. Self-medication, incomplete antibiotic courses, and obtaining antibiotics without a physician's prescription were also frequently reported.

Ordinal logistic regression showed that students from non-bio-science faculties and those who practiced self-medication were less likely to report higher self-rated knowledge of antibiotic use. Self-rated knowledge was also associated with antibiotic use practices, with students reporting moderate or poor self-rated knowledge showing higher odds of belonging to higher-risk antibiotic use practice categories than those reporting good self-rated knowledge. However, this association should be interpreted cautiously because knowledge was assessed using participants' self-ratings rather than an objective measure of antibiotic knowledge.

The findings suggest that misconceptions regarding antibiotic use and suboptimal antibiotic use practices may occur among students in this study despite generally good awareness of the role of antibiotics in treating bacterial infections. The observed associations between academic background, self-medication behavior, and self-rated knowledge, together with the relationship between self-rated knowledge and reported antibiotic use practices, provide further insight into antibiotic use behaviors within this university setting. Although these findings should be interpreted in light of the study's cross-sectional design, single-university setting, and reliance on self-reported measures, they may contribute to understanding antibiotic use behaviors among university students in Bangladesh. Further multi-institutional studies incorporating objective assessments of antibiotic knowledge would be valuable for better understanding antibiotic use behaviors and evaluating the generalizability of these findings.

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Modeling and Forecasting GDP per Capita in Bangladesh using ARIMA Model

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Abstract: Gross Domestic Product per capita represents the overall value of goods and services produced within a country over the course of a year, divided by the total population of that country. It is measured using constant price GDP data to track real growth over time. The study employs GDP per capita data for the period 1991-2023, as cross-checking across multiple credible sources showed the highest consistency in these years, whereas earlier data appeared comparatively dispersed and less reliable. There are many studies that used only post-2000 GDP data too few for reliable model training while pre-1991 data remain inefficient and inconsistent across sources, even though the 1991-2023 period provides the most dependable series and this study emphasizes this gap by focusing on a longer, more reliable dataset to ensure stronger forecasting validity. Using the Box-Jenkins methodology, this study tries to forecast future values of GDP per capita data for the next decades. After conducting statistical analysis and diagnostic checks, ARIMA (0,2,1) model was determined to be the best fit. A steady increase in economic growth leads to higher average incomes and plays a crucial role in reducing poverty. Notably, this economic indicator shows an upward trend, indicating improvements in living standards and overall national progress in future years.

Keywords: GDP per capita, Box-Jenkins, ARIMA, Forecasting, Bangladesh.

1. Introduction

As a fundamental measure of economic performance, GDP per capita outlines the average value of output per person, serving as an indicative measure of individual income levels. Simply, GDP per capita is calculated as the total value of goods and services produced by resident producers for final use, divided by the midyear population. It excludes the depreciation of physical capital and the depletion of natural resources, as noted by the World Health Organization (WHO, 2025). GDP per capita growth is widely used to express the overall economic progress of a country, and it can also reflect the income scenario of individuals within that country, as discussed by James et al., (2012). During the independence of Bangladesh in 1971, the growth of GDP per capita was not satisfactory even after decades of the post-independence period. However, after 1990, Bangladesh's GDP, along with GDP per capita, increased noticeably, indicating improved economic progress, as shown by Miah et al., (2019).

Though GDP per capita as an economic variable was not remarkably influenced during the COVID-19 pandemic in 2020 and 2021 as the obtained data showed, other economic variables such as inflation and interest rates showed noticeable dispersion. Since GDP per capita is influenced by many other variables, this study aimed to examine how GDP per capita alone can describe its future values using time series analysis, without incorporating other factors. Several studies, including Ahsan, (2024); Kassa et al., (2019); Radek & Viktar, (2022), have highlighted the importance and limitations of GDP per capita, reinforcing its significance as a key macroeconomic indicator for policy formulation.

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To analyze its behavior, we applied the Autoregressive Integrated Moving Average (ARIMA) model following the Box-Jenkins approach. Various models were constructed by adjusting the parameters p , d , and q , representing the autoregressive component, the degree of differencing, and the moving average component, respectively an approach earlier applied by Ning et al., (2010), Ahmed & Ar Salan, (2020); Voumik & Smrity, (2020). The most suitable model was selected using several model selection criteria, primarily the Akaike Information Criterion (AIC), while also considering the Bayesian Information Criterion (BIC), consistent with the guidelines provided by Gujarati, (2003). After selecting the model, we performed diagnostic checks to identify the best-fitting specification and used it to forecast GDP per capita values for the coming decades, similar to methods adopted by Sharma et al., (2022). We concluded the study by presenting the key findings and providing recommendations for policy development in the context of Bangladesh's economic advancement.

2. Literature Review

Several studies have been conducted to observe Bangladesh's economic performance, particularly focusing on the variables GDP and GDP per capita. GDP per capita is nowadays widely used and considered a significant determinant of living standards, as it provides insight into the economic well-being of a population (Harvie et al., 2009). Its global monitoring and ease of calculation make it a key measurement for economic analysis. Changes in GDP per capita directly influence a country's economic stability, making it a crucial factor to study (Bergeaud et al., 2020).

Nevertheless, several researchers point out that GDP per capita has limitations as an indicator of economic progress (Giannetti et al., 2015). Research shows that nations with significant income inequality and high levels of economic freedom may experience lower actual development than what their GDP per capita figures suggest. Additionally, a larger shadow economy negatively affects the gap between GDP per capita and the Human Development Index (HDI), suggesting that GDP per capita may not fully capture economic and social progress Radek & Viktar, (2022).

Bangladesh has shown remarkable economic growth in recent years, with a rising GDP per capita signaling significant development. Understanding this growth is essential for shaping policies that could help Bangladesh transition into a developed nation (Salma et al., 2020). The increasing nature of GDP per capita can potentially predict the well-being of economic performance, specifically in the perspective of Bangladesh (Voumik & Smrity, 2020).

(Sharma et al., 2022) showed forecasted values of India's GDP per capita for the next 10 years using the ARIMA model. ARIMA is a popularly used time series forecasting technique for analyzing univariate time series variables, and prior research suggests it can effectively predict GDP per capita (Ahmed & Ar Salan, 2020).

Although several studies analyze Bangladesh's GDP trends, many rely solely on post-2000 data or use inconsistent pre-1991 data, leaving a gap for a reliable long-period forecast based on the most consistent 1991-2023 GDP per capita series. Understanding and forecasting GDP per capita is essential for assessing Bangladesh's long-term economic progress and for supporting effective policy planning aimed at improving national living standards.

3. Methodology

3.1. Sources of Data

Bangladesh's GDP per capita data, covering the period from 1991 to 2023, was mainly sourced from the World Development Indicators provided by the World Bank. For ease of access and visualization, Macrotrends was also consulted, which presents World Bank-sourced data.

3.2 Autocorrelation function

The Autocorrelation Function (ACF) gives the measurement of the correlation between observations in a time series that are separated by various time lags. It plays a vital role in understanding the structure of a time series, as it quantifies both the direction and the strength of the statistical relationship between values at different points in time. Specifically, the ACF at lag k , denoted by ρ_k , is computed as:

$$\rho_k = \frac{\gamma_k}{\gamma_0} = \frac{\text{covariance at lag } k}{\text{variance at lag } 0}$$

When ρ_k is plotted against lag k , the output graph is referred to as the population correlogram.

However, in practical applications, we often only calculate the sample autocorrelation function (SACF), denoted as $\hat{\gamma}_k$, and the sample variance $\hat{\gamma}_0$. These defined as follows:

$$\hat{\gamma}_k = \sum \frac{(y_t - \bar{y})(y_{t+k} - \bar{y})}{n} \text{ and}$$

$$\hat{\gamma}_0 = \sum \frac{(y_t - \bar{y})^2}{n}$$

Here n is the size of the sample and $\bar{y}$ indicates the sample mean.

Thus, the sample autocorrelation function at lag k is defined as,

$$\hat{\rho}_k = \frac{\hat{\gamma}_k}{\hat{\gamma}_0}$$

This represents the ratio of the sample covariance to the sample variance. When $\hat{\rho}_k$ is plotted against the lag, the resulting graph is known as the sample correlogram. The time series which is stationary, the autocorrelation at various lags should generally remain around zero. Violating this refers to be nonstationary.

3.3 Partial autocorrelation function (PACF)

The Partial Autocorrelation Function (PACF) is similar to the concept of a partial regression coefficient in multiple regression analysis. In a k -variable regression model, the regression coefficient of k th variable β_k represents the rate of changes in the mean value of the dependent variable for a unit change in the k th independent variable X_k , while considering the influence of all other independent variables as constant.

In the similar way, the partial autocorrelation ρ_{kk} measures the correlation between observations that are k time period apart, after accounting for the correlation at all intermediate lags. In other words, the PACF is the correlation between Y_t and Y_{t-k} after eliminating the influence of the intermediate value of Y at lags between t and $t - k$.

3.4 Unit root test

The Unit Root test is a statistical method used to assess whether a time series is non-stationary or stationary. A time series is considered nonstationary if it contains a unit root, meaning its statistical properties such as mean, variance, and autocorrelation change over time. A widely used test for stationarity is the unit root test. Let's consider model, $y_t = \rho y_{t-1} + \mu_t$

Where, μ_t is a white noise error term.

Starting from the equation above, we can subtract y_{t-1} from the both sides,

$$y_t - y_{t-1} = \rho y_{t-1} - y_{t-1} + \mu_t$$

On simplification,

$$\therefore \Delta y_t = (\rho - 1)y_{t-1} + \mu_t = \delta y_{t-1} + \mu_t$$

This is the model to estimate, where, $\delta = \rho - 1$. The hypotheses of interest are:

The Null Hypothesis $H_0 : \delta = 0$; implies the series has a unit root. The Alternative Hypothesis $H_a : \delta < 0$; implies the time series is stationary.

3.5 Phillips-Perron Test

Peter C. B. Phillips and Pierre Perron introduced a non-parametric statistical technique designed to handle potential serial correlation in the residuals without the need to include lagged difference terms. As the Phillips-Perron (PP) test shares the same asymptotic distribution as the Augmented Dickey-Fuller (ADF) test statistic, it follows a procedure that is largely similar to that of the ADF test.

3.6 Autoregressive integrated moving-average (ARIMA) model

The time series models are usually on the assumption that the time series involved are stationary. But if the time series is not stationary then it need to be differenced. If a time series need to be differenced d times to make stationary then the time series is called integrated of order d , $I(d)$. Therefore, when a time series needs to be differenced d times to achieve stationarity before fitting an $ARMA(p,q)$ model, the resulting model is referred to as an $ARIMA(p,d,q)$ model.

3.7 Box-Jenkins methodology

It is an interesting art to find best ARIMA model. It is an iterative process that involves various steps. Which can be outlined in the following Figure 1:

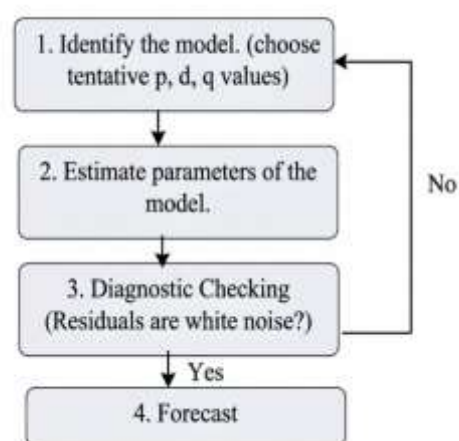


Figure 1 Flow Chart of Box-Jenkins methodology

4. Results

4.1 Plot of the Data

At first, we plot the original series to see the pattern in the data. The characteristics of line indicates an important aspects of time series analysis which is stationarity. Nonstationary series generally shows trend, seasonality or cyclical pattern. If the series is nonstationary then we transform it to make stationary. Figure 2 shows a positively increasing pattern or a trend which indicates possible non-stationarity. And Figure 3 is the plot of first differenced series and there are also slight positive trend and shows the possibility of having unit root or the series may be nonstationary. In the Figure 4, the second differenced series show a constant fluctuation around zero thus an indication of possible stationary series.

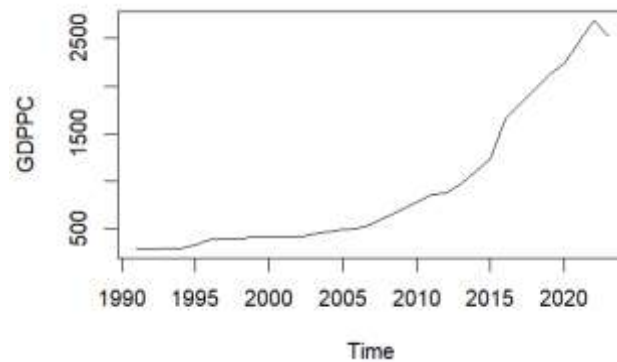


Figure 2 Plot of original GDP per capita

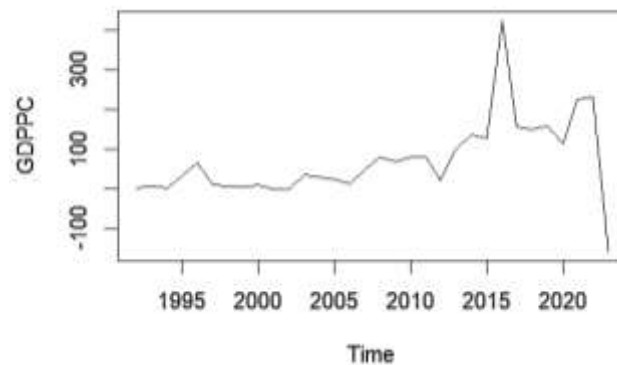


Figure 3 Plot of first differenced GDP per capita

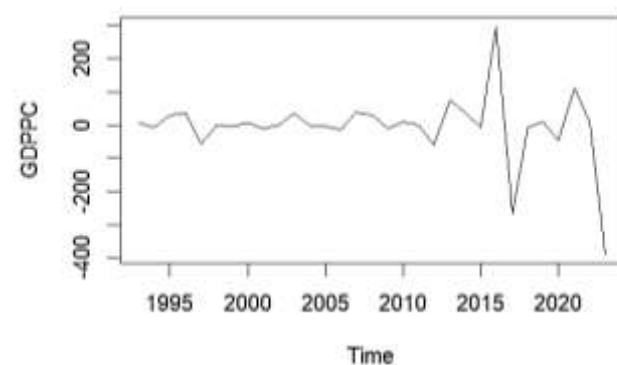


Figure 4 Plot of second differenced GDP per capita

4.2 Auto Correlation and Partial Correlation

The plot of autocorrelation and partial autocorrelation can provide an indication of stationarity. Figure 5 shows ACF and PACF of original series which is produced using R environment. Where ACF shows gradually decaying pattern or geometric pattern and PACF resulting a significant spike at lag 1, which is an indication of non-stationary series. Eviews 12 output shows similar pattern as previous and the probability values are significant and also the ACF decays slowly and the PACF cuts off sharply, so the series is considered as non-stationary.

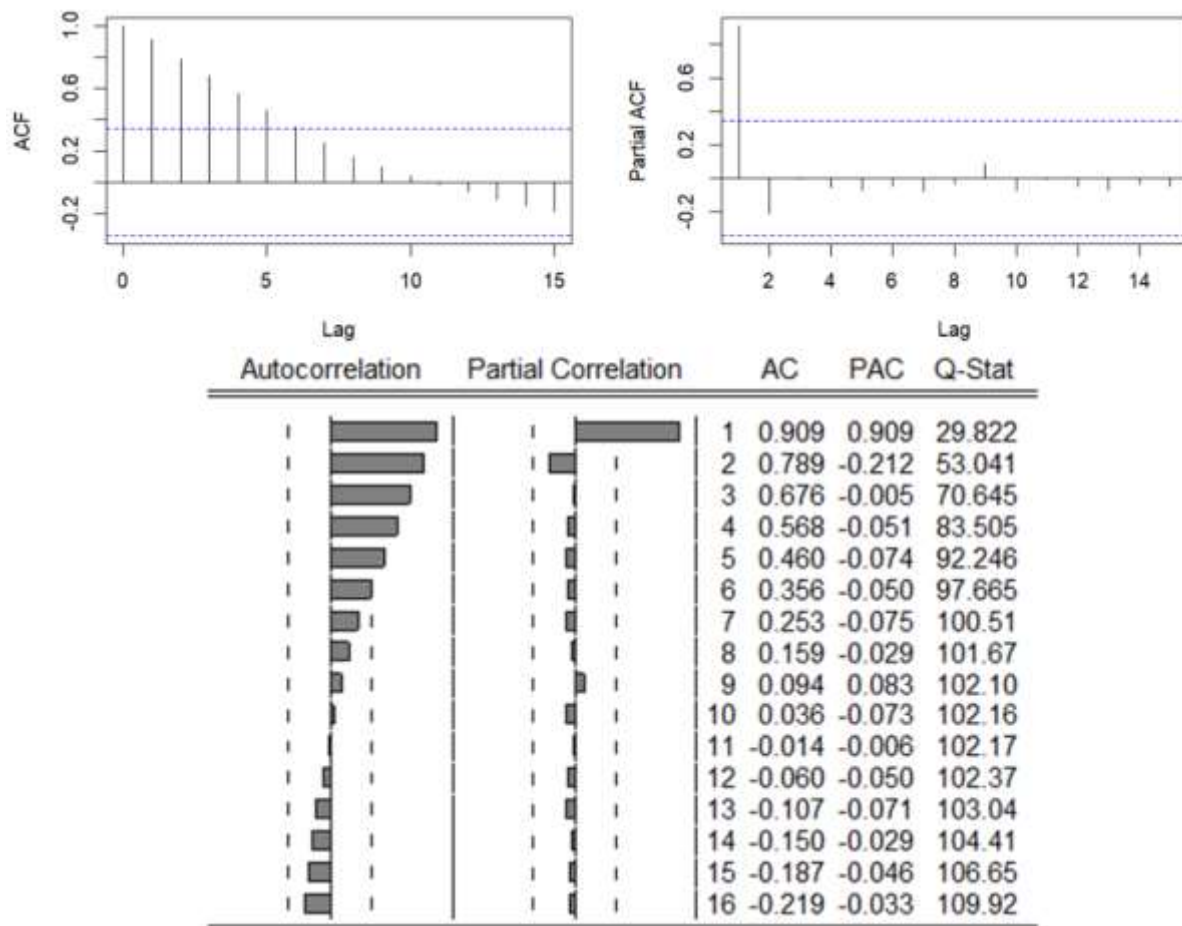


Figure 5 ACF and PACF of Original Series

Both these graphical representation and probability values are indicating the series to be nonstationary.

4.3 Test of Unit Root

To be ensured that the series is nonstationary, we performed Phillips-Perron test of unit root. And the following is the output:

Table 1 Phillip-Perron Test of Unit Root

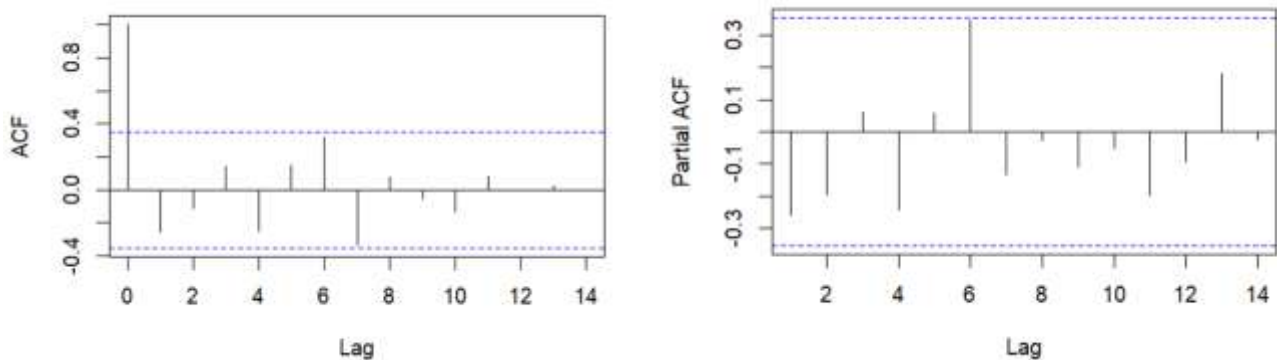
Phillip-Perron Test Statistic	Original Series		First Differenced Series		Second Differenced Series	
	Adj. t-Stat	Prob.	Adj. t-Stat	Prob.	Adj. t-Stat	Prob.
	2.049	0.9998	-2.8070	0.0641	-6.2432	<0.001**
Test Critical Values						
1%	-3.6537		-3.1082		-3.7302	
5%	-2.9571		-2.9207		-2.9925	
10%	-2.6174		-2.5187		-2.6320	

Original Series is non stationary at 1%, 5% and 10% level of significance since the critical value 2.049 is greater than all critical values (

Table 1). And also, the p-value is insignificant, so we cannot reject the null hypothesis, which means the series has a unit root thus it is nonstationary. Then the first differenced series is also showing that it is nonstationary. And second differenced series shows that the series is stationary. So the time series GDP per capita is integrated of order 2, that means $I(2)$.

4.4 ARIMA Model Identification

After being confirm that the time series is $I(2)$, we check the ACF and PACF of $I(2)$ series. Which is presented in the following Figure 6:

**Figure 6** ACF and PACF of Second Differenced Series

The ACF exhibits a significant spike at lag 1, on the other hand PACF shows no significant spikes, suggesting a potential $MA(1)$ process. This leads to the initial selection of an $ARIMA(0,2,1)$ model.

4.5 Finding Optimum ARIMA (p,d,q) Model

$ARIMA(0,2,1)$ model output presented in the Table 2.

Table 2 Output of ARIMA(0,2,1)

Parameter	Estimate	Standard Error
MA(1)	-0.7098	0.1596
σ^2 estimated	Log Likelihood	AIC
8525	-185.62	373.25

The ARIMA (0,2,1) model shows estimated variance (σ^2) is 8525, and the model's log-likelihood and AIC values are -185.62 and 373.25, respectively, suggesting a reasonable fit. However, further model comparison and residual diagnostics are needed.

We have fitted several models and tried to find out the most appropriate model using criteria like Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). As the lower the AIC value, the better the fit.

Table 3 AIC and BIC Value of Different Model

Model	AIC	BIC
ARIMA(1,2,0)	377.1719	380.0399
ARIMA(0,2,1)	373.2488*	376.1167*
ARIMA(2,2,0)	375.1022	379.4042
ARIMA(2,2,1)	376.8217	382.5576
ARIMA(2,2,2)	378.1547	385.3246
ARIMA(0,2,2)	375.2475	379.5494
ARIMA(1,2,1)	375.2480	379.5499

Lowest value of AIC and BIC outlining best model is ARIMA (0,2,1) among these other models. Thus, we select ARIMA (0,2,1) model based on lowest AIC value for further checking diagnostics to ensure that this model is the best model for forecasting.

4.6 Checking Diagnostics of Residuals

4.6.1 Plot of Residuals

First, we plot the residuals to see the pattern.

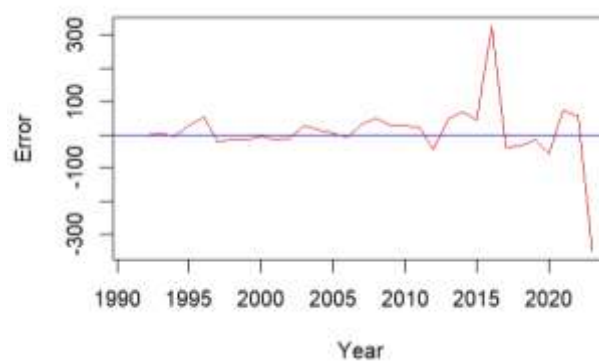
**Figure 7** Residuals of the ARIMA (0,2,1) Model

Figure 7 shows that the residuals are scattered around 0 with a constant fluctuation. Which is the indication that the residuals are stationary.

4.6.2 Unit Root Test of Residuals

Based on the Phillips-Perron unit root test, obtained $Z - \tau = -4.2035$, at 1% and 5% level of significance, we reject the null hypothesis of non-stationarity for the critical values -3.65 and -3.95 respectively. So, we can conclude that the series has no unit root and residuals are stationary, as the value of Z -tau is significantly below the critical values.

4.6.3 Test of Autocorrelation of Residuals

Table 4 Ljung Box Test Results

Ljung-Box test Errors from ARIMA (0,2,1)		
Q*	df	p-value
10.007	6	0.1244

A p-value of 0.12 exceeds common significance levels such as 0.05 or 0.01, leading us to fail to reject the null hypothesis of no autocorrelation in the residuals. This implies that there is no statistically significant autocorrelation present, suggesting the model has effectively captured the underlying structure in the data.

4.7 Forecasting

After checking residuals of the model and conforming best fit for the GDP per capita data between time period 1991 to 2023, we can use ARIMA (0,2,1) model for further prediction for next 10 years.

Table 5 Forecasted Values for the Next Decade

Year	Point Forecast	Lower Interval (95%)	Higher Interval (95%)
2024	2617.364	2436.399	2798.33
2025	2705.649	2410.252	3001.046
2026	2793.933	2382.78	3205.086
2027	2882.217	2349.653	3414.782
2028	2970.502	2309.813	3631.19
2029	3058.786	2263.039	3854.533
2030	3147.07	2209.386	4084.755
2031	3235.355	2149.012	4321.697
2032	3323.639	2082.111	4565.167
2033	3411.923	2008.883	4814.963

The forecasted values in Table 5, which is graphically showing in Figure 8 indicating an increasing state of per capita GDP which is an indication of the prosperity of economic status of Bangladesh.

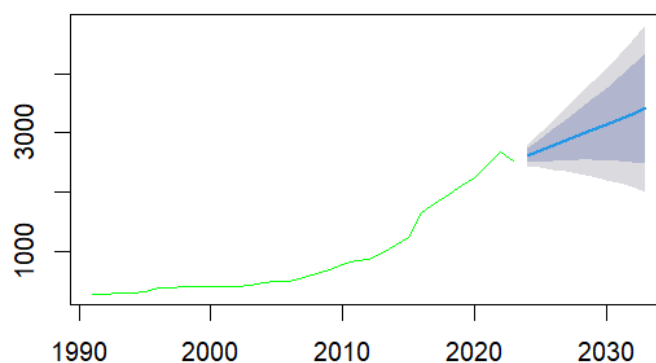


Figure 8 Forecasting GDP Per Capita in Bangladesh

The green line shows the observed values and the blue line shows the forecasted values. Forecasted values show an upward trend which is suggesting an increasing GDP per capita as the year goes.

5. Discussion

This study applied the Box-Jenkins ARIMA framework to Bangladesh's GDP per capita (1991-2023), identifying ARIMA(0,2,1) as the most parsimonious and statistically robust specification. The series found integrated of order two, $I(2)$. This aligns with Miah et al., (2019), who documented strong upward GDP trajectories following Bangladesh's growing era. Model selection was guided by both AIC and BIC, which consistently favored ARIMA(0,2,1) over other competing specifications, supporting the principle of parsimony (Voumik & Smrity, (2020)). The MA(1) structure is consistent with the classical single-spike ACF pattern of the second-differenced series, while residual diagnostics the Phillips-Perron test ($Z\text{-tau} = -4.20$) and Ljung-Box test ($p = 0.12$) confirmed white-noise residuals free from autocorrelation, corroborating findings by Voumik & Smrity, (2020) and Ahmed & Ar Salan, (2020). Forecast accuracy was validated by the close agreement between the predicted 2024 GDP per capita (USD 2,617) and the IMF-reported figure of USD 2,624 an error below 0.3% consistent with Sharma et al., (2022). Forecasts project GDP per capita reaching approximately USD 3,147 by 2030 and USD 3,412 by 2033, supporting Bangladesh's upper-middle-income aspirations. As emphasized by (Radek & Viktar, 2022), GDP per capita does not capture distributional equity or informal sector dynamics, underscoring the need for multivariate approaches in future research.

6. Limitations

This study focused exclusively on a single economic indicator GDP per capita and did not incorporate other macroeconomic variables that may significantly influence GDP dynamics. As a result, the findings are based solely on univariate forecasting and ignore the broader interactions among economic factors. The analysis was conducted entirely using R programming language and Eviews, and only a limited set of statistical procedures was applied to reach the conclusions. Furthermore, the study relied on secondary data sources, meaning that real-time or primary data were not included, which may affect the precision and immediacy of the forecasts.

7. Conclusion

This study provides the evidence of a steady progress of Bangladesh's economy, as reflected by the upward trend in GDP per capita and the accurate performance of the ARIMA (0,2,1) forecasting model. The results suggest that if other factors and conditions remain stable, Bangladesh's economic status is likely to continue improving over the next decade. These findings are reflecting for the country's long-term growth and its aspiration to become a developed nation in the future. However, to maintain and strengthen this positive flow of economy, policymakers should consider the influence of other macroeconomic factors that also contribute to rising GDP per capita. Future research can further enhance the reliability of forecasts by incorporating additional variables or adopting more advanced modeling techniques.

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