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EQUITY AND INCLUSION: MAINSTREAMING SMALL ETHNIC COMMUNITIES IN THE CHITTAGONG HILL TRACTS, BANGLADESH

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Abstract

This paper examines equity and inclusion in development initiatives affecting Small Ethnic Communities (SECs)[1] in Chittagong Hill Tracts (CHTs), Bangladesh, through a rural development project supported by Asian Development Bank (ADB) as a case study. Using a multi-method approach, the study analyzed relevant policies and legal instruments, geopolitical conditions, project records and primary data were collected through field observations and key informant interviews. Results show that sustained engagement with SECs through participatory consultations, village mapping, and context-specific interventions were essential to achieve development goals with customary practices within a dual legal system. This was accomplished by following the national legal frameworks in Bangladesh, in collaboration with the safeguard policies of development partner. Interventions, such as improvement of road network, market sheds, gravity flow distribution of water, promotion of local medicinal plant cultivation along with drawing on indigenous knowledge in creating alternative income opportunities enhanced the income and quality of life as well as facilitated in sustaining their cultural practices. These experiences demonstrate how alignment of safeguard principles, local practices, and participatory approaches can foster more inclusive outcomes, contributing to global development agendas in Bangladesh such as SDG 10 on reducing inequalities and SDG 17 on partnerships for the goals.

Key words: CHTs, Participatory planning, Livelihood, Community consultations, Land Tenure, SDG.

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1 In Fifteenth Amendment to the Constitution of Bangladesh Act, 2011 (Act XIV of 2011), section 14, Article 23A refer to tribes, minor races, ethnic sects and communities. This paper will refer to the small ethnic communities in CHTs as SECs and IP as international context.

Introduction

Bangladesh is a country in the north-eastern part of South Asia bounded by the Himalayas to the north and the Bay of Bengal to its south. Majority of the land area is delta plain, with only hilly ranges are to the south-east in the Chittagong Hill Tracts (CHTs). Three districts Khagrachari, Rangamati and Bandarban of the south-eastern part of Bangladesh with extensive hilly landscape covering 13,184 sq.km. area, nearly one tenth of the total area of Bangladesh (UNPO, 2018) (Fig. 1). The area accommodates nearly 1,842,815 population of which half of the population, 920, 217 people are from SECs representing nearly 56% of the total ethnic population of Bangladesh (BBS, 2022). The terrain condition of this region is less favorable for high density human population and therefore, despite being a densely populated country, the number of populations is the minimum in this region (Khan *et al.*, 2007). In contrast with the plain land area in Bangladesh, the population density is only 136 persons per sq km for CHTs, whereas average density for the rest of the country is 1,179 persons per sq km (BBS, 2022). The recent census showed these three districts have the least density of population with 260 (Khagrachari), 107 (Bandarban) and 106 (Rangamati) people per sq km compared to the national average (BBS, 2022). Historically, this region accommodates eleven ethnic communities according to the government documentation (Khatun and Aggarwal, 2019; UNPO, 2018). Chakma, Marma and Tripura comprise the largest proportion at 46%, 29% and 13% of the local ethnic population (UNDP, 2009).

For a significant period, the CHTs was seen as an isolated region to remain in solitude. The people living in these hill districts are spread out in remote "*Para's*" within the hilly terrain. The complex geopolitical history of CHTs dates back to the British colonial period; as prior to British rule, the administration and resources in this area were entirely managed according to the customary rules of the ethnic communities. In 1860, the CHTs was designated as a separate subdivision under Chittagong. Later, the pivotal Chittagong Hill Tracts Regulation Act of 1900 marked the regional boundary and maintained a system of governance that combined traditional and national administrative structures (Ahammad and Stacey, 2016). Since then, the region has grappled with the challenges posed by this dual administrative system and its associated complexities. The construction of the Kaptai Dam forcibly displaced SEC inhabitants, triggering a prolonged and violent armed conflict that concluded with the signing of the 1997 Peace Accord. (Khatun and Aggarwal, 2019; Rasul and Thapa, 2006; Ahammad and Stacey, 2016).

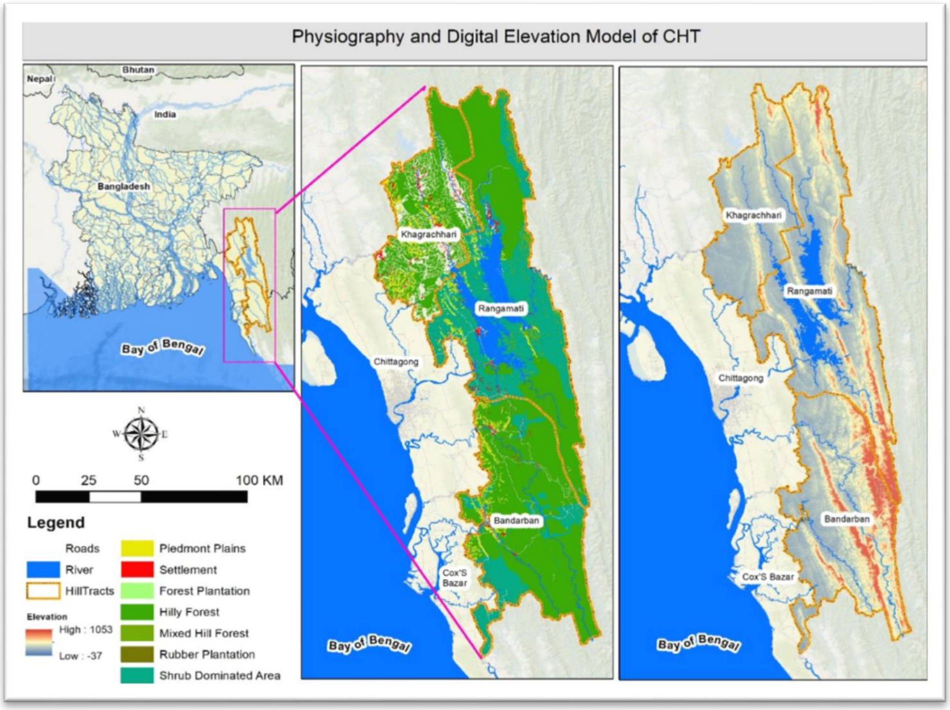

Fig. 1. Physiographic Characteristics of the CHTs
(Source: Landcover data used from Ahmed and Rubel, 2013)

In this context, the first phase of Chittagong Hill Tracts Rural Development Project (CHTRDPI) was initiated in 2001 by the Government of Bangladesh (GoB) in partnership with the Asian Development Bank (ADB). This project was a major step by the government to build trust and implement the commitments made through the peace accord. However, the development needs and demands in the region were too significant to be addressed with a single project intervention. Therefore, a second phase of the project (CHTRDPII), from 2011 to 2022 was implemented by integrating with ADB Safeguards Policy Statement (SPS) 2009 (ADB, 2009) with the objective of development of infrastructures pertinent to improve rural livelihood with special attention to the ethnic communities and reducing poverty and vulnerability among the people of the CHTs.

Based on propositions from communities and assessments, the project aimed to intervene in five specific areas that include (i) institutional development and capacity building; (ii) upgraded rural roads, (iii) development of community infrastructure, (iv) micro agribusiness development, and (v) project management. In this context the project faced challenges in compensating the affected persons led by acquisition of land for infrastructure development. This article reviews the project initiatives and experiences as a case and exhibit the findings to identify implications and challenges of implementing a development project with development partner safeguards policy in a community with diverse ethnicity, complex geo-political demography, inequalities and dual legal system in terms of land ownership rights. It will also shed light on how development partner's safeguard policy and facilitation acted as catalyst in mainstreaming and reducing inequalities to SECs in CHTs through a development project.

Literature Review

The governance of land acquisition and customary rights in Bangladesh has undergone significant legal transformations over the decades. The Acquisition and Requisition of Immovable Property Ordinance (ARIPO) 1982 (MoL, 1982) initially provided the legal framework for land acquisition, later replaced by the Acquisition and Requisition of Immovable Property Act (ARIPA) 2017 (MoL, 2017). While ARIPA 2017 introduced more structured compensation mechanisms and expedited processes, it remains insufficient when evaluated against international standards on social safeguards issues. ARIPA focuses predominantly on monetary compensation based on land records, often neglecting the socio-cultural and livelihood impacts of displacement on affected communities including SECs and other vulnerable groups. Moreover, key principles like participatory decision-making, recognition of customary land tenure, and inclusive grievance mechanisms are absent in the Act and its amendments.

In contrast, the United Nations Declaration on the Rights of Indigenous Peoples asserts indigenous land rights (Article 26), cultural heritage (Article 11), and free, prior, and informed consent (FPIC) (Article 32), reinforcing the need for inclusive land governance (United Nation (UN), 2007). International development partner policy principles, such as the ADB's Safeguard Policy Statement (SPS), emphasize consultation, livelihood restoration, and cultural heritage preservation in land acquisition and resettlement. However, gaps between national laws and international standards hinder equitable development. A draft National Policy on Involuntary Resettlement and Rehabilitation (NPIRR) developed in 2009 with support from ADB, aimed to align national practices with global safeguards by promoting fair compensation, livelihood restoration, and stakeholder engagement (Zaman and Khatun, 2019; Zaman *et al.*, 2022), which was not legalized due to non-alignment with the national policy.

An in-depth description of the historical, legal, and social dimensions of land rights in the CHTs was provided by Ray (2000) in her book. Ray highlights the marginalization of SECs through the erosion of their traditional rights, particularly due to colonial-era regulations such as the Chittagong Hill Tracts Regulation Act of 1900 and subsequent development initiatives like the Kaptai Dam construction. She also underscored the ongoing challenges posed by dual land tenure systems, including disputes over governance and resource allocation and emphasized the need for participatory approaches to policymaking, advocating for equitable recognition of customary practices and meaningful inclusion of ethnic communities in decision-making processes. Building on these discussions, Feiring, (2013) in Indigenous People's Rights to Lands, Territories, and Resources examines the broader international legal frameworks governing indigenous land rights. Feiring (2013) further broadens this perspective by examining international legal frameworks on indigenous land rights, emphasizing the collective nature of indigenous tenure systems and the frequent failure of mainstream legal systems to accommodate them.

Globally, similar challenges and best practices have emerged concerning the recognition of Indigenous People's (IP) land rights within development interventions. Gilbert (2006) documented how large-scale land investments in Tanzania and Kenya devoid of adequate recognition of customary tenure, resulted in widespread dispossession and marginalization of indigenous communities. Likewise, Larson et al. (2013) identified that in the context of REDD+ programs, insecure land tenure systems often excluded indigenous communities from equitable benefit-sharing. These international experiences reflect parallel patterns of exclusion observed in the CHTs of Bangladesh.

In the CHTs, historically unique governance systems, including self-rule under ethnic community chiefs, were undermined during colonial rule and further disrupted in post-1947, during Pakistan's regime (Rasul, 2007).The conflicts escalated significantly with construction of the Kaptai Dam in early 60s and displaced nearly 100,000 inhabitants, stripping them of their ancestral lands and livelihoods (Zaman, 1982; Adnan, 2008; Rasul and Thapa, 2006). The bitterness resulting from this event persisted until the birth of Bangladesh (1971) and continued until it to an end with the signing of a peace accord in 1997 (Khatun and Aggarwal, 2019; Rasul and Thapa, 2006; Ahammad and Stacey, 2016). Despite the signing of the peace accord, socio-political unrest, economic marginalization, natural resource conflicts and lack of recognition of customary rights persist (Adnan, 2007; Ahammad and Stacey, 2016; Khatun and Kabir, 2019).

Scholars have argued that genuine recognition of indigenous rights requires integrating indigenous knowledge systems, governance structures, and socio-cultural identities into development frameworks (Ulfstein, 2004). Hill *et al.* (2020) advocate for inclusive assessments that incorporate indigenous, local, and scientific knowledge, while Hill *et al.* (2012) emphasize that the superficial participation without giving the indigenous people the decision -making power perpetuates systemic exclusion. Schlosberg and Carruthers (2010) similarly argue that environmental justice for indigenous communities requires addressing their historical marginalization and enhancing their decision-making capabilities.

Evidence from Latin America further affirms that securing indigenous land tenure has positive socio-economic and environmental outcomes. Blackman *et al.* (2017) demonstrated that land titling of indigenous communities in the Peruvian Amazon significantly reduced deforestation and strengthened community governance. Reyes-García *et al.* (2022) also emphasized that recognition of indigenous peoples' rights is essential in achieving the post-2020 Biodiversity Agenda, linking tenure security with sustainable resource management and cultural preservation.

These international perspectives reinforce the specific context of the CHTs, where socio-economic indicators illustrate systemic marginalization. Rasul and Tripura (2016) revealed significant disparities in poverty rates, access to basic services, and health indicators between the CHTs and national averages (Table 1). For instance, in 2009, the poverty rate in the CHTs stood at 62% compared to the national average of 32% (Rasul and Tripura, 2016). Barakat et al. (2009) further reported that the average annual household income in the CHTs was only 72% of the national average, with significant livelihood challenges rooted in limited access to services, political instability, and customary land tenure disputes.

The geographical and socio-cultural uniqueness of CHTs, characterized by hills, valleys, lakes, and diverse ethnicities (Rashid, 2019; UNPO, 2018), compounds these development challenges. Remoteness, low population density, and historical conflict have constrained educational and economic development. Subsistence farming (Shelly, 2000), particularly shifting cultivation *(jhum)*, remains the dominant livelihood for many SECs inhabitants (Khan *et al*., 2007).

From global to local context, it is evident that without recognizing customary land rights, ensuring meaningful community participation, and establishing equitable benefit-sharing mechanisms, development interventions can reinforce structural inequalities. The experiences of other indigenous communities across continents highlight the need for a rights-based, culturally sensitive, and inclusive approach for development in the CHTs and beyond.

Table 1. Social Wellbeing Indicators in the CHTs Compared to National Average.

Social Indicators	Average for three hilly districts	National average
Poverty rate	62 (2009)	32 (2010)
Population in extreme poverty 2010	26.2	17.6
Access to suitable source of drinking water	65	75
Prevalence of Anaemia (till 05 years)	62	49
Use of improved drinking water sources	59	98
Use of household based sanitation facilities	35	56

Source: Rasul and Tripura, (2016)

Methodology

This study adopted a multi-method approach to assess the issues of equity and inclusion in development initiatives affecting SECs in the CHTs of Bangladesh. The study involved a comprehensive analysis of policy and legal frameworks, a review of the geopolitical context of the CHTs, and an examination of relevant project documents alongside the requirements of the Asian Development Bank's (ADB) Safeguard Policy Statement (SPS) (ADB 2009).

Primary data were collected through field observations of the researchers and key informant interviews (KIIs). In addition, records of focus group discussions (FGDs), and community consultations were assessed from project documentations. A total of 13 KIIs were conducted with project beneficiaries, local stakeholders, and community leaders. These endeavors focused on evaluating the level of community engagement, grievance redress mechanisms, and the extent to which ethnic perspectives were incorporated into project planning. The KIIs were conducted across eight locations representing all three hill districts of the CHTs; Rangamati, Khagrachari, and Bandarban. The selected sites ensured spatial representation of both upland and valley communities, capturing variations in livelihood practices, governance structures, and social inclusion dynamics. All KIIs were conducted with the prior informed consent of participants, ensuring voluntary and ethical participation.

In addition to the KIIs, records from community consultations and FGDs conducted during project implementation were reviewed. Although the social structure in the CHTs remains largely patriarchal, women play a central role in household management and economic activities (Khatun and Kabir 2018). Accordingly, the project placed particular emphasis on women's participation across age groups and social settings. Insights from these engagements were integrated into project design, site selection, and implementation planning.

This integrated methodological approach ensured a comprehensive understanding of SECs development needs and facilitated the incorporation of community-driven priorities into both project execution and academic analysis.

Results and Discussion

The findings of this paper illustrate that direct engagement with ethnic communities during the implementation of the rural development project in CHTs was instrumental in promoting equity and inclusion. This engagement was made possible through the national legal frameworks in Bangladesh, in collaboration with safeguard policies of development partner.

Although the NPIRR was prepared in 2009 with ADB support, it was not formally adopted by the GoB. Nevertheless, this collaborative effort resulted in significant positive changes to national land acquisition laws, specifically enhancing the recognition of customary rights. This progress was reflected in the enactment of the Chittagong Hill Tracts (Land Acquisition) Regulation (Amendment) Act, 2019 (MoL, 2019), which introduced compensation parity between customary land and registered land ownership.

Community consultations and FGDs provided insights into socio-cultural challenges in the CHTs, including access to drinking water, mobility during rainy seasons, and agricultural transport in dry seasons (ADB, 2022). Key concerns included customary land rights, and administrative complexities, reflecting aspirations to balance cultural heritage with technological progress. Participatory Village Mapping (PVM) was a critical tool fostering community engagement (ADB, 2022) and sustainable development through Para Development Committees (PDCs) (United Nations Development Programme (UNDP), 2019). Remoteness exacerbated economic challenges, with reliance on shifting cultivation *('Jhum'*) with limited irrigation and market access. Successful initiatives aligned with SECs practices and regional characteristics. Female FGD participants in Ruma, Raicha-Goalikhola, and Marishya Bazar emphasized the impact of localized interventions like the gravity-flow water system in addressing water scarcity, reducing seasonal migration, and enhancing agricultural productivity, ultimately improving long-term economic sustainability for SECs communities (ADB, 2022), which has been also confirmed by the KII participants.

Cognizance of Local Practices and Inclusion

In the domain of community engagement within development projects, the UNDP has played a pioneer role in CHTs area through formation of PDCs. Since 2003, UNDP has been at the forefront of development initiatives in the region. Their collaboration with local NGOs has been crucial in facilitating the delivery of services and shaping community-level administrative systems to align with regional development goals. By 2019, over 3,500 PDCs had been established across the CHTs. This formed a wide-ranging community network and the collaboration of ADB and PDCs extensively supported governance at grassroot level and ensured development in line with community empowerment (UNDP, 2019).

During preparatory assessments for CHTRDP-II between 2006 and 2010, remoteness had been identified as a major factor contributing to the economic vulnerability of SECs. Livelihood practices were found to differ based on topographical conditions. Households residing in higher hill areas primarily depended on shifting cultivation *('jhum'*), while valley dwellers engaged in plough-based agriculture such as rice farming. Access to markets, transportation of agricultural produce, and water scarcity were recognized as significant challenges in the CHTs. In particular, the difficulty in using tube-well technology due to terrain and groundwater limitations posed serious constraints on access to drinking water and irrigation in the hilly areas. KIIs highlighted that interventions, such as introduction of *Bashok* plant and other local medicinal plant cultivation, drawing on indigenous knowledge created alternative income opportunities while sustaining cultural practices. Beneficiaries also noted that improved market sheds and transportation support reduced barriers to selling their produce. Visual evidences collected during project implementation illustrates these challenges and KII results provide a similar finding. During the field visits by the researchers, it was observed in remote areas of CHTs that farmers transporting harvested produce over slippery, rugged roads during the rainy season and manually cleaning turmeric after harvest, reflecting the physical hardships faced by ethnic communities in the CHTs.

Institutions involved in various consultation meetings at multiple phases of the project expressed that ethnic communities are aware of their evolving needs to sustain their presence while navigating cultural differences, migration, and generational shifts. These initiatives have fostered opportunities but also raised concerns about cultural dilution and the transmission of SECs knowledge. KIIs confirmed that, for the first time, communities felt their customary land rights were acknowledged and that they could directly shape development priorities. Respondents emphasized that inclusive participation improved their ability to balance livelihood improvements with cultural preservation, thereby reinforcing both economic security and social identity. The community's aspirations reflect a dual goal: equipping the younger generation with economic opportunities while preserving cultural heritage and identity.

Community consultations also revealed the significant socio-cultural role of women. Although the social structure largely follows a patriarchal system, women were identified as central actors in household management, water collection for household activities and drinking in addition to other economic activities. During preparatory consultations, efforts were made to structure the project in alignment with traditional values. Multi-level stakeholder engagement led to the establishment of institutional arrangements, marking the first instance in Bangladesh where the Project Management Unit (PMU) was based in the CHTs under the Regional Council, ensuring SECs' representation in decision-making (ADB 2022, United Nation (UN) (2007). In line with Feiring's (2013) recommendations for participatory governance, the selection of project schemes followed the Participatory Village Mapping (PVM) method. Through this approach, communities actively identified resource distribution, settlement patterns, and priority intervention areas. Work packages remained small-scale, allowing local bidders to manage implementation effectively and to ensure economic participation for the local vendors.

Changing Socio-economic Context

Project interventions in the CHTs achieved varying success in promoting sustainable socio-economic development, with initiatives aligned to ethnic practices and local ecological conditions proving more effective. A key example was the promotion of Malabar nut plantations as a viable agribusiness, which secured a supply agreement with a national pharmaceutical company, ensuring market access for local producers. The project also enhanced diversified marketed crops from two to ten including mango, litchi, Indian gooseberry, brinjal, cucurbits, Malabar nut, Aswagandha, and Kalomegh enhancing food security and income opportunities. Additionally, access to water, a major challenge especially for women, was improved through a gravity-flow distribution system, reducing water collection time from 1.5 hours to 30 minutes. This intervention eased women's workload and helped to mitigate seasonal migration among SECs, often driven by water scarcity during dry periods. The key informants also highly appreciated the gravity flow distribution of water. They added a new dimension of this act, it facilitated more girls to attend the school regularly, while many of them had to give more time in collecting water for the family, mainly in dry season by compromising school hour.

The project's economic impact analysis (ADB, 2022) showed substantial livelihood improvements, with commercial agricultural production increasing by 239% from baseline figures. Beneficiary households observed annual agricultural incomes rising from BDT 20,000 to 67,885, while 29,378 households benefited from infrastructure interventions. Watershed management and irrigation schemes improved agricultural productivity for 37,526 households, facilitating a shift from single to double cropping across 11,568 hectares. The KII interviews affirmed this positive trend in the locality very distinctly. These outcomes highlight the project's role in fostering economic growth, improving livelihoods, and promoting sustainable agriculture while remaining sensitive to SECs socio-cultural contexts.

Navigating Challenges in Dual Legal Systems

Despite the project's positive outcomes, a major challenge was navigating customary rights and land acquisition within a dual legal system. This was further complicated by the absence of a precedence for systematically applying land acquisition policies in this framework. Understanding the administrative structure of the CHTs is crucial. The CHTs' governance structure is characterized by overlapping authorities. Historically, the Deputy Commissioner (DC) serve as the chief executive under the Chittagong Hill Tracts Regulation of 1900. The establishment of three Hill District Councils (HDCs) in 1989 introduced a parallel governance system composed of locally elected representatives, including reserved seats for ethnic groups (Ray, 2000). While HDCs oversee local development, the DC retains authority over revenue and land matters. This creates a complex legal-administrative landscape with overlapping responsibilities. In addition, the role of village headmen narrowed down to largely address internal disputes for managing customary land at community level.

During project preparation, the Acquisition and Requisition of Immovable Property Ordinance, 1982 (MoL, 1982) lacked provisions for compensating the customary land. The only legal mention was in the 1900 Regulation, which vested tenure management in tribal leaders without recognizing individual ownership. Acknowledging this gap, the project allocated funds from ADB for compensating both registered and customary landowners, a pioneering step in Bangladesh's development history (ADB, 2022).

However, administrative delays arose due to the absence of precedent cases. Payments to registered landowners proceeded smoothly, but customary landowners faced delays. Eventually, coordination with the Ministry of CHTs Affairs (MoCHTA) facilitated compensation disbursement, reflecting a significant step towards recognizing customary land rights within formal land acquisition processes.

Strategic Approaches in Strengthening Collaboration

The case of the CHTRDP II project portrays measures that go beyond national land acquisition policies, including livelihood restoration, community consultations, grievance redress mechanisms and formation of an alternate dispute resolution forum to mitigate land related disputes. Participatory approaches implemented through ethnic-led Community-Based Organizations (CBOs) and local NGOs ensured that resettlement and capacity-building initiatives were responsive to community needs and aligned with international good practice. KII respondents in different levels acknowledged the continuous consultations, approvals from local governance bodies, and consent from tribal leaders facilitated the project in addressing challenges related to coordination, language, and administrative complexities in compensating both registered and customary land.

Livelihood restoration prioritized agricultural capacity development, enhancing skills and equitable access to benefits, thereby advancing SDG 10 (reduced inequalities). Strengthened collaboration with local organizations and inclusive decision-making processes fostered knowledge sharing and collective action, supporting SDG 17 (partnerships for the goals). National reforms, such as ARIPA 2017, Chittagong Hill Tracts (Land Acquisition) Regulation (Amendment) Act, 2019, and subsequent local regulatory updates, provided a legal framework reinforcing participatory and equitable implementation of resettlement processes.

Conclusion

This paper highlights the importance of inclusive, community-driven approaches for implementing rural development project in the complex socio-political and legal landscape of the CHTs. Structural barriers like undulating landscapes, limited access to resources and markets, remoteness, and the historical marginalization of small ethnic communities (SECs) have long constrained sustainable development. Evidence from the project as well as responses of the KIIs shows that participatory planning, sustained community consultations, and recognition of customary land rights can directly address these constraints when embedded in project rules and decision-making (Ahammad and Stacey, 2016).

A key achievement was to institutionalize the formal acknowledgment of customary land tenure, by establishing compensation parity between customary and registered landholders, in CHTs. This step advances SDG 10 on reducing inequalities and protecting customary rights, while the project's collaboration among government institutions, financing partners, and SEC institutions embodies SDG 17 on partnerships (United Nations, 2015a; United Nations, 2015b). The initiative also contributed to incremental legal reforms, including application of the Acquisition and Requisition of Immovable Property Act (ARIPA) 2017 and amendments to the CHTs Land Acquisition Regulation, setting a precedent for integrating customary rights into formal acquisition procedures (MoL, 2017; MoL, 2019). These advances are consistent with international standards, notably the United Nations Declaration on the Rights of Indigenous Peoples and scholarly work underscoring the centrality of secure customary tenure for equity and cultural continuity (United Nations, 2007; Gilbert, 2006; Feiring, 2013; Ulfstein, 2004).

Overall, the CHTs experience demonstrates the transformative potential of sustained policy advocacy, inclusive governance, and culturally sensitive design to mainstream SEC rights within national development. Continued attention to co-created grievance redress, transparent monitoring, and capacity support will be essential to consolidate these gains and extend equitable development in similarly marginalized regions**.**

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A NEW SPECIES OF SLENDER CRAB-SPIDER OF THE GENUS *TIBELLUS* SIMON, 1875 (ARANEAE : PHILODROMIDAE) FROM BANGLADESH

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Abstract

The paper contains a taxonomic description (added: including diagnosis and illustration) of a new species of slender crab-spider of the genus *Tibellus* Simon, 1875 from Bagerhat, Bangladesh. The species *T. bagerhatensis* n.sp. was identified as new to science. Generic diagnosis and distributions are also provided together with the description of the new species.

Key words: Taxonomy, Slender crab-spider, *Tibellus bagerhatensis,* Araneae, Philodromidae, Bangladesh.

Introduction

The spiders of the family Philodromidae F. O. Pickard-Cambridge, 1871 are commonly known as 'Slender crab- spiders'. They are usually found on the grasslands and on the shrubs of small gardens. Earlier these spiders belonged to the subfamily Philodrominae under the family Thomisidae Sundevall. Homann (1975), on the basis of some important morphological and molecular-genetic characters, separated subfamily Philodrominae from the family Thomisidae and established 'the Philodromidae' as a full family. At present, the family Philodromidae is composed of 29 genera and 527 valid species worldwide (World Spider Catalog, 2024).

The members of the genus *Tibellus* Simon, 1875 are commonly known as 'long-bodied grassland crab-spiders'. These are small to medium in size with long, slender body and legs. The spiders under this genus are widely distributed and till date the genus contains a total of 53 valid species occurring in the world fauna (World Spider Catalog, 2024). The genus *Tibellus* was first erected by Simon in 1875 with Holarctic species *Aranea oblonga* Walckenaer, 1802 as type-species. The records of the study on these spiders in Bangladesh are scarce except Okuma *et al.* (1993), Biswas (2009 , 2019) and Biswas and Raychaudhuri (2003), but a good number of species are recorded and described in other countries of the world, like – India (Tikader, 1960, '62, '71, '80; Gajbe & Gajbe, 1999),

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China (Song & Zhu, 1997; Zhao, 1993; Song *et al*., 1999), Korea (Kim & Jung, 2002; Kim & Seong, 2015; Jang *et al.*, 2023), Japan (Yaginuma, 1986; Ono, 1988), the Philippines (Barrion & Litsinger, 1995), USSR (Mikhailov, 1997; Efimik, 1999; Danilov, 1991; Utotschkin 1981, '84), Israel (Levy, 1977), France (Millot, 1942; Walckenaer, 1802), USA (Gertsch, 1933; Platnick, 1997), Africa (Van den Berg & Dippenaar-Schoeman, 1994; Dippenaar-Schoeman, 2022) etc. The present paper contains description of a new species *Tibellus bagerhatensis* n. sp. together with the generic diagnosis and distribution.

Materials and Methods

Collection and Preservation: The specimens of the new species were collected from the garden of south-western coastal village Betaga, district Bagerhat, Bangladesh. The collection was made by jarking the branches of shrubs to an inverted umbrella placed underneath the plants. The two specimens (one male and one female) thus collected, were then transferred to a large glass jar containing a wad of cotton soaked with chloroform for anesthetizing specimens. These were then carried to the laboratory and placed in a petri dish with 70% ethyl alcohol for sorting and cleaning. The specimens were then placed separately in glass vials containing 70% ethyl alcohol for identification and study. After identification, the specimens were preserved (single specimen in single vial) permanently in Audmans' Preservatives following Lincoln and Sheal (1985).

Identification and Study: The specimens thus preserved were identified by the study of different important taxonomic characters, viz. body shape, size, colour, dorsal decoration, eye patterns, segmentation and spination of legs, cheliceral structure and dentition, characters of maxillae, labium, sternum, spinnerets, male pedipalps, female epigynum etc. All these were done following the keys and taxonomic descriptions made by Gertsch (1933), Tikader (1960, '62, '80 ,'87), Ono (1988),Kaston (1972),Barrion and Litsinger (1995), Dondale and Redner (1978), Levy (1977), Van der Berg and Dippenaar-Schoeman (1994), Song and Zhu (1997), Zhao (1993), Yaginuma (1986) and Biswas (2009). The specimens were identified up to the genus *Tibellus* which was confirmed from the Arachnida section, Zoological Survey of India, Kolkata.

For the identification up to species level, taxonomically important body-parts of the specimens were dissected out under a Stereozoom Binocular Microscope placed on a petri dish filled with 70% ethyl alcohol and sand grains. Male palps after dissection were boiled in 10% KOH solution for 3-5 minutes for relaxation and extension of different parts. Female epigynum after dissection, placed in clove oil for 12 to 18 hours for clearing of its different parts (Levi, 1965; Tikader, 1987). After that, both the male palp and female genitalia (epigynum) were placed in separate microvials and put in a large vial along with the parent spider within Audmans' Preservatives.

Illustrations: The whole body of the spider and its different body-parts were illustrated under the Stereozoom Binocular Microscope (Mention model) fitted with Camera Lucida and other necessary accessories. Leg measurements were taken under the same condition in the following sequences : femur, patella, tibia, metatarsus, tarsus and total length. All the measurements were taken in millimeters (mm).

The morphological and anatomical characteristics of the collected specimens were compared with other species of *Tibellus*, but there was no match for any of the species under the genus *Tibellus*. It was, therefore, thought that the collected specimens mightbelong to new species under the genus *Tibellus*. Later on, I consulted with the experts on spiders in India and Bangladesh, and after meticulous observation on the collected specimens, they were also of the opinion that the said specimens belonged to a new species under the genus *Tibellus*.

The naming of the new species was done following the rules of the International Commission on Zoological Nomenclature (ICZN). The new spider species has been named "*bagerhatensis*" based on the type-locality of Bagerhat. It was mentioned in `Etymology' and the procedure of establishing it as a new species is described in detail in the remarks.

Type deposition: After completion of necessary drawings and measurements of different body-parts, the types (Holotypay and Allotype) of specimens were put separately with the collections of the Department of Zoology, Khulna Government Women's College, Khulna and later on, these specimens will be deposited to the Museum of the Department of Zoology, University of Dhaka, in due course of time.

Results and Discussion

Taxonomy

Family: PHILODROMIDAE F. O. Pickard-Cambridge, 1871
Genus: ***Tibellus***Simon, 1875
Type-species: *Aranea oblonga* Walckenaer, 1802

1875. *Tibellus* Simon, *Les Arachnides de France*, **2**: 307.
1895. *Tibellus*: Simon, *Hist. Nat. Araign.,* **1**(4) : 1065.

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1960. *Tibellus*: Tikader, *J. Bombay nat. Hist. Soc.*, **57**(1): 176.
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1997. *Tibellus:* Song & Zhu, *Fauna Sinica, Araneae, Philodromidae*, : 209.
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1999. *Tibellus*: Gajbe & Gajbe, *Rec. zool. Surv. India*, **97** (3): 191.
2002. *Tibellus:* Kim & Jung, *Korean Arachnol.,* **17**(2): 208.
2003. *Tibellus:* Biswas & Raychaudhuri, *J. Bombay nat. Hist. Soc.,***100**(1) : 84.
2015. *Tibellus:* Kim & Seong, *Korean Arachnol.*, **31**(1): 11.
2023. *Tibellus:* Jang *et al*., *Anim. Syst. Evol. Divers*, **39**(4): 272.
2024. *Tibellus: World Spider Catalog*, Version 25.0, online at – http ://www. wsc.nmbe.ch. (accessed on 7th October, 2024).

Diagnosis: The spiders of the genus *Tibellus* Simon, 1875 are usually small. The body is distinctly elongated, flattened and slender. A long mid-dorsal brown stripe present from the anterior of the carapace up to the end of abdomen. Total body length ranges from 5.70 mm to 11.00 mm. Carapace longer than wide, yellow-brown, rather low smoothly convex at lateral margins, approximately 2.80 mm long and 2.35 mm wide; with a distinct brown median longitudinal stripe and sometimes with a pair of lateral stripes present. Eyes small, black, approximately uniform in size and grouped close anteriorly; posterior row of eyes strongly recurved; posterior median eyes (PME) distinctly closer to each other than to posterior lateral eyes (PLE). Legs long, slender, laterigrade, yellow, without any band and well-developed scopulae and claw-tufts; leg IV longer than the I and II. *Abdomen* elongate, slender, yellow with light brown mid-dorsal longitudinal stripe or band and sometimes with one or two pairs of dark spots. Pappal tibia of male with or without small retrolateral apophysis and usually with small simple ventral apophysis. Embolus short, spur-like, situated at distal end of tegulum. Epigynum of female with median septum that varies species to species. Spermathecae ovoid or kidney-shaped.

Biological Note: Representatives of genus *Tibellus* are usually found extending the elongate and slender body on the tall grasslands or ferns and similar herbs in the fields and small shrubs in the gardens. It becomes difficult to detect them sometimes because the striped body is pressed close to the stem and legs are extended/ stretched anterior and posteriorly. They cannot move quickly and consume prey in a shorter distance.

Members of *Tibellus* cannot spin any web and also cannot jump like other spiders but move slowly over grasslands and foliage of small plants in the gardens. They are good predators of smaller insects in the crop-fields and gardens. In the crop-fields, maximum numbers of these spiders are found in the grasses of boundaries.

Distribution : ASIA, EUROPE, AMERICA and AFRICA .

Description of new species:

***Tibellus bagerhatensis* n. sp.**

(Figs. 1a-1i)

Material examined: **Holotype**: 1 male, Bagerhat, 12. V. 2012, Coll. V. Biswas; **Allotype**: 1 female, Bagerhat, 12. V. 2012 & 18. VII. 2014, Coll. V. Biswas; Paratype: Nil.

Designation of type: The male spider on which the present description and illustrations have been made is herein designated as Holotype and the other female spider specimen is designated as Allotype.

Holotype: This is a single male specimen preserved permanently in Audmans' preservatives. It was collected from a deep garden of village Betaga, district Bagerhat (Type locality) and later an illustrated description was made on the basis of its important taxonomic characters.

Allotype: This is a single female specimen collected from the same locality and from the same spot (shrub). Its epigynum (female genitalia) is drawn to show the female identifying character of the new species.

General: Both male and female spiders collected are morphologically similar except body measurements and sex organs. The body is small, soft, nearly brown in colour. Cephalothorax and legs light brown; abdomen brownish with deep brown, long striae. Total body length of male (holotype) 3.90 mm, Carapace 1.65 mm long, 1.00 mm wide, 0.85 mm height; abdomen 2.25 mm long, 0.70 mm wide and 0.30 mm height. Total body length of female (allotype) 4.20 mm. Carapace 1.72 mm long, 1.20 mm wide, 0.92 mm height; abdomen 2.42 mm long, 0.95 mm wide and 0.42 mm height.

Cephalothorax: Broad, nearly oval, anteriorly narrowing with straight marginally and posteriorly broad, medially wide. Eyes white, heterogeneous, each encircled with black basal band; lateral eyes largest, both median eyes are small; anterior row nearly straight and the posterior row strongly procurved; ocular quad narrowing anteriorly (Fig. 1a). Chelicerae brown, strong, margined with chitinous ridge (Fig. 1b). Maxillae brown, elongate, anteriorly broad and scopulate (Fig. 1c). Labium brown, medially wide, basally flat and anteriorly scopulate (Fig. 1c). Sternum light brown, long, anteriorly wide, margin concave and posteriorly pointed (Fig. 1d). Legs long and slender, not so strong, with sharp spines and setae; leg formula 1423 and measurements (in mm) are shown in Table 1.

Table 1. Measurements (in mm) of different leg segments of *Tibellus bagerhatensis* n. sp.

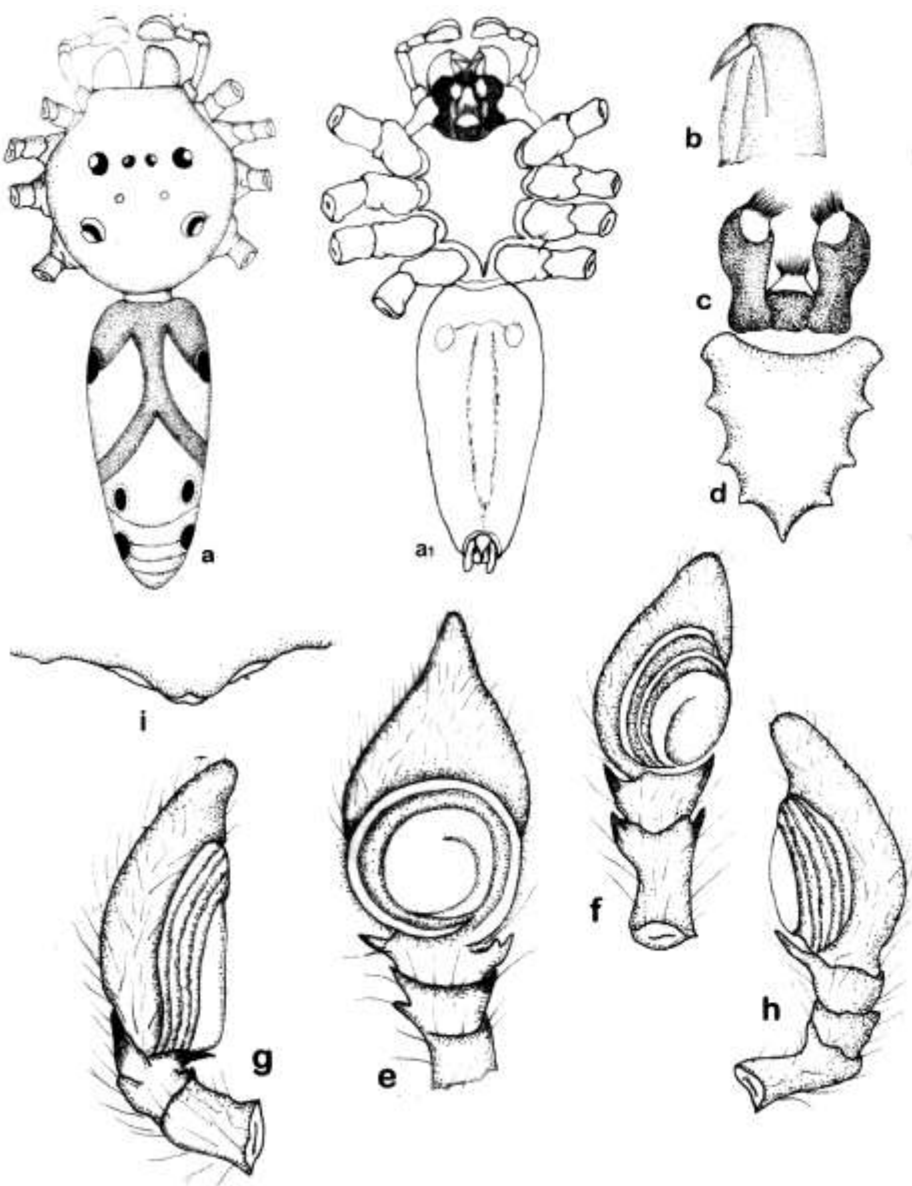
Leg	Femur	Patella	Tibia	Metatarsus	Tarsus	Total
I	2.25/2.25	0.65/0.65	2.10/2.10	1.60/1.60	1.10/1.10	7.70/7.70
II	1.40/1.40	0.30/0.30	1.20/1.20	1.00/1.00	0.60/0.60	4.50/4.50
III	1.50/1.50	0.40/0.40	1.10/1.10	1.00/1.00	0.50/0.50	3.70/3.70
IV	1.50/1.50	0.40/0.40	1.30/1.30	1.20/1.20	0.40/0.40	4.50/4.50
Palps	0.40/0.40	0.20/0.20	0.30/0.30	-	0.65/0.65	1.55/1.55

Males are a little smaller than females but same in colour and appearance. Male palps with sharp cymbium and apophysis, tegulum coiled (Fig. 1e-1g).

Abdomen: Broad, elongate, nearly dumbbell-shaped, anteriorly wide ; dorsum decorated with long striae and three pairs of black spots or sigillae (Fig. 1a). The abdomen of male is also the same as the colour and decoration of a female. Epigynum blunt, lip-like (Fig. 1h).

Etymolog: The species is named according to the name of the type-locality from where the specimen was collected.

Distribution: Bangladesh : Gardens of village Betaga, district Bagerhat (type-locality).



Figures 1 (a-i): *Tibellus bagerhatensis* n. sp.

a. Whole body (dorsal view); a1. Whole body (ventral view); b. Chelicerae; c. Maxillae & Labium; d. Sternum; e. Male palp (ventral view); f. Male palp (retrolateral view); g-h. Male palp (lateral view, left & right); i. Female epigynum

Remarks: Species *Tibellus bagerhatensis* n. sp. appears close to *T. shikerpurensis* Biswas & Raychaudhuri (2003) in appearance but may easily be separated out by the following characters –

1. Cephalothorax broad, medially wider and nearly rounded.
2. Maxillae, labium and sternum structurally different.
3. Abdominal dorsum with 3 pairs of sigillae and much different decoration and
4. Typical chelicerae, epigynum and pedipalps.

Also, none of the already described *Tibellus* species (Tikader, 1960, ’62; Gertsch, 1933; Levy, 1977; Biswas, 2009; Biswas & Raychaudhuri, 2003; Efimik, 1999; Jang *et al.,* 2023; Van der Berg & Dippenaar-Schoeman, 1994) resemble with the present one.

The species, is therefore, described as new to science.

Discussion

The new species *Tibellus bagerhatensis* n. sp. is a small, elongate and unique slender crab-spider found in the grassland and shrubs of gardens of Bangladesh. It shows some special diagnostic characters on the basis of those it is established as a new species. Due to these important characteristics, we may expect that there are some considerable numbers of endemic species present in different areas of the country.

From this record, it is also found that till date, only 2 (two) species have been recorded and described on this genus (including the present one). Therefore, a detailed taxonomic study on this genus may be undertaken to know the total species composition of the genus *Tibellus* in Bangladesh.

Moreover, we also know that the slender crab-spiders are distributed both in the garden and different crop-fields. So, it is assumed that these spiders may have a good predatory role in controlling the pest insects of both these ecosystems (like other crab-spiders).

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PROBIOTIC EFFECTS ON TIGER SHRIMP (*PENAEUS MONODON*) GROWTH AND WATER-SEDIMENT QUALITY OF GHERS IN BAGHERHAT, BANGLADESH

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Abstract

Probiotics are live microorganisms which enhance shrimp productivity and maintaining favourable water and soil qualities. This study was conducted to ascertain the effect of three probiotics on shrimp growth, feed utilization, survival, water and sediment qualities in coastal ponds of Bagerhat, Bangladesh. Twelve ponds were selected and divided into four treatment groups as T_1 (Miracure), T_2 (Biozyme), T_3 (Rapidgrow) and T_4 (control-without probiotics) with same stocking densities of 6 PL/m². Shrimp were feed 30% protein (Mega feed Ltd.) thrice daily at 5-10% of body weight for 120 days. Growth performance, shrimp biomass and feed utilization increased significantly ($p<0.05$) in probiotics treated groups, especially Miracure, compared with the control. It was observed that probiotic treated ponds showed significantly improved shrimp growth performance (32.2-38.5%), survival (14-18%) and lower FCR (33.5-38.7%) compared to control ponds. NH_3 decreased significantly ($p<0.05$) in probiotics treated ponds compared to control ponds. Significant improvement of sediment parameters (organic matter, total nitrogen, phosphorus and potassium) was observed in probiotics treated ponds. Probiotic application also exhibits water and sediment qualities by higher total heterotrophic bacteria (THB) and lower *Vibrio* species, contributing to overall health status of the shrimp ponds. This study reinforces the importance of probiotics as a long-lasting adoption for enhancing shrimp farming in Bangladesh. All future research should be focused on the effects of probiotics. The extent of benefits is the curtail of chemicals used in aquaculture at the coastal and marine environment.

Key words: White gold, Feed conversion ratio, Total heterotrophic bacteria, Organic matter, Total nitrogen, Phosphorus

Introduction

Coastal aquaculture, encompassing both shrimp/prawn and finfish farming, has been expanding in Bangladesh's coastal regions. Efforts have also been directed at establishing a business-friendly supply chain with a strong focus on hygiene and safety standards for fish, shrimp and fishery products destined for both domestic and international markets.

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These interventions have led to a rise in total shellfish production and prawn production, including both wild and farming, 175,000 metric tons in 2003-04 to 271,000 metric tons in 2022-23 (DoF, 2024). Shrimp farming holds significant prominence due to its economic value and widespread cultivation across coastal regions of the world. In this regard, the black tiger shrimp (*Penaeus monodon*) emerges as the key commercial species, making a significant contribution to the global seafood export (DoF, 2024). The GDP growth in fisheries sector of Bangladesh in 2024 was 2.45 percent and the contribution of the fisheries sector in the overall agriculture sector was 21.68 percent (DoF, 2024).

For shrimp farming in particular, beneficial bacteria namely probiotics are emerging as an effective alternative to antibiotics. Probiotics are usually referred to as live microbial feed additives that help in maintaining a healthy microflora in the environment (Fuller, 1989). They can be used in aquaculture either as food additives or in water treatment (Moriarty, 1998). Probiotics use in aquaculture serve various functions, including inhibiting pathogenic bacteria by producing antimicrobial compounds, improving water parameters, boosting defense mechanism of the vector organism, and supplementing the vector's diet through production of additional enzymes (Verschuere *et al*., 2000). Studies have demonstrated that the lactic acid bacteria can increase the survival of shrimp exposed to *Vibrio harveyi* (Vieira *et al*., 2010).

Probiotic use in shrimp culture has been a subject of great interest over the last decade. A number of studies have been operated to explore the significance of probiotics on growth, survival, disease resistance, and water quality in various farming systems (Pal *et al*., 2010). In aquaculture, research on probiotics has primarily focused on in vitro models to assess their effectiveness in combating pathogens (Wang *et al*., 2008). These supplements enhance nutrient utilization by providing enzymes that improve the digestibility of dietary components, thereby facilitating better nutrient absorption in the host. As the push for environmentally sustainable aquaculture continues to grow, probiotics are increasingly recognized as a vital component of such systems (Moriarty, 1998; Gatessoupe, 1999). Although several commercial probiotics such ProbioAqua, Magic, SP super and Miracure, are available both liquid and granulated forms, many farmers, especially in Bangladesh, lack sufficient knowledge about their proper use and benefits. Islam *et al.* (2013) has explored the application of probiotics in shrimp farming within brackish water environments as broader utilization of probiotics in Bangladesh's fish farms.

The range of commercial probiotic products used in aquaculture around the world, whether as feed or water additives, showed a great deal of variation in terms of their effectiveness, pricing, and significant rates of ineffectiveness in some of the items. The effective use of probiotics in aquaculture, however, depends in large part on the method of administration (Jahangiri and Esteban, 2018) and the probionts. Non-beneficial probiotics may even be detrimental to fish/shrimp species; in addition, they may result in greater financial losses (Hai, 2015). This highlights the need for investigation into the effectiveness of probiotics in diets, particularly for shrimp farming. Considering the issue, this research had been undertaken to assess the effects of probiotics on shrimp growth performance, output and water-sediment qualities in farming system in coastal Bangladesh.

Materials and Methods

Area of study and period: The research work was performed in twelve brackish water shrimp ghers in the Bagerhat Sadar, Bagerhat. The ponds were of an average size of 400 m^2, ranging from 0.9 to 1.6 meters in depth. The duration of the research was one culture period, March - July 2023.

Experimental design: The experiment included four treatments: T_1 (Miracure), T_2 (Biozyme), T_3 (Rapid grow), and T_4 (without probiotics) each applied in three replicates. Stocking density of shrimp PL was six (6) individual per square meter. Dose of selected probiotics was 0.5 g per kg of supplied feed in each treatment without T_4. Probiotics mixed with feed very properly and carefully, and then supplied to the experimental ponds.

Preparation of waterbodies and management of water: Each of ponds was left to dry as well as crack such that the hydrogen sulfide can be oxidized and kill fish eggs, crab larvae, snail larvae, and other predators. The top 30 cm of surface soil was removed from each pond to release harmful gases, oxygenate the bottom soil, and improve soil fertility. Using a cone-type pH meter (Hanna 8424), the soil pH was measured, averaging 6.8 across the ponds. To neutralize the acidic soil and increase nutrient availability, lime (CaO) was used at a dose of 250 kg/ha. Waterbodies were subsequently fulled tidal water from Bhairab river to a depth of 60 cm, allowing one or two days for sedimentation. Afterward, ponds were treated with fish killing substance (rotenone-3 ppm) to eliminate trashed organism, followed by lime (CaO) at 125 kg/ha to neutralize the rotenone's effect. Following 5 days of cleaning, ponds were inoculated with urea and TSP (urea- 50 kg/ha and TSP-100 kg/ha) after being cleaned for five days. Water turned green after four to five days. Around ponds, fine mesh nylon net was placed to guard against potential carriers of disease that could enter into shrimp ponds, like snails, snakes, and other animals. 25-50 kg/ha of lime (CaO) was added with water of culture ponds from time to time every 7 to 15 days to adjust the pH level during the culturing period.

Shrimp PL stocking: All ponds were stocked with hatchery produced post larvae (PL) of *Penaeus monodon* (average body weight, 0.006 g) at a uniform density of 6 individuals per square meter. Prior to stocking, the PL were carefully acclimated to the pond water. Shrimp PL were purchased from Foyla bazar in Rampal, Bagerhat. Shrimp PL were transferred from market to the study location in oxygenated polythene bags. Bags submerged in the research waterbodies for a period of thirty minutes to permit water circulation among the pond and the bags to adjust the PL to pond water temperature prior to releasing the PL into the ponds. The PL were stocked in the experimental ponds after acclimatization. The weight and length of 30% of the PL were moved separately using digital balance and scale and released to the ponds.

Supplement diet: The stocked shrimp post-larvae fed a Mega feed from gradually lowering amount, starting at ten percent of their total weight and reducing to 5%, thrice a day at 06:00 am, 13:00 pm and 19:00 pm until the day before harvest. The composition of the supplied feed was moisture-11%, crude protein-30%, crude lipid -7%, ash- 15%, crude fiber-8% and carbohydrate- 29%.

Feeding protocol and growth measurement: Commercial Mega floating feed was used as the food for the shrimps. The feed started at 10% of the body mass of the shrimps and slowly reduced to 5% over the duration of the study. Quantity of feed was splited into three portions given equally on a daily basis at specific intervals: morning, noon and evening. Feed levels were alternated each 15 days according to body weight fluctuation of the shrimp. Shrimp behavior was carefully monitored, especially following morning and evening feeding, to assess their condition, including movement, infection, coloration, and diseases, if any. Net used to assess shrimp growth, with fortnightly sampling to record the individual number and their body weight. Five to seven hauls were conducted in each pond to monitor shrimp health, signs of disease, color, and average body weight. Sampling continued regularly until harvest.

Probiotics selection, water and sediment qualities monitoring: Three brand names of probiotics as Miracure, Rapid Grow, and Biozyme were selected for the experiment. These were sourced from Fish Tech Pharmaceuticals, located at Shahjalal Upashahar, Sylhet. Environmental parameters such temperature, transparency, pH, salinity, DO, total alkalinity as well as ammonia nitrogen were analyzed every 7 days at 10 am of each sampling excursion. Salinity was determined using a portable refractometer (ATAGO, Hand Refractometer) and pH was determined through pH meter (Hanna Instruments, HI 8010, Japan). In situ temperature of water was measured with a common Celsius thermometer, and the DO concentration was recorded by DO meter (YSI 58 digital DO meter, HANNA, Yellow Springs, Ohio 45387 USA). Transparency was found through a Secchi disc. Total alkalinity was analyzed by titrimetric methods (APHA, 1992), and ammonia concentration calorimetrically determined, as described by Strickland and Parsons (1968) and APHA (1992). Sediment cores were collected from all the ponds at three sampling sites during culture: initial (before stocking), mid-term (60-day culture), and final term (120-day culture). The samples were dried under the air, ground into granulated form, and stored in airtight bags. These analysed for pH, organic matter, nitrogen, phosphorus, and potassium in the laboratory of the Soil Research Development Institute (SRDI), Sylhet.

Bacteria estimation: The total heterotrophic bacteria (THB) and *Vibrio* species loads were assessed monthly. Water and soil samples aseptically collected through various ponds promptly transported to research place. The THB load was determined through the pour plate method using plate count agar as the culture medium, following the standard protocol outlined in APHA (1992) in the Water and Soil Quality Lab of Shrimp Research Station, BFRI, Bagerhat. The load of *Vibrio* species was also measured using the pour plate technique, employing thiosulfate citrate bile salts (TCBS) agar medium. The bacterial load in each sample was calculated with a standard formula and reported as colony-forming units (CFU) per milliliter or gram of the sample.

Harvesting and growth parameters: After a 120-day culture period, leaves and bamboo poles were taken out and ponds drained for harvest of shrimp through frequent netting operations (seine net plus cast net). Every shrimp taken from each pond was individually counted, measured, and weighed. Survival rate (%), specific growth rate (SGR) and food conversion ratio (FCR) were calculated following the equation as cited by Pechsiri and Yakupitiyage (2005).

The equations are as follows:

Status of growth and feed utilization as weight gain = (Mean final weight (g) − Mean initial weight (g),

SGR = {Ln (final body weight)−Ln (initial body weight) × 100}/cultured period (days)

FCR = (Feed consumed (g dry weight)/live weight gain (g wet weight) of shrimp)

Survival rate (%) = (No. of shrimps harvested ÷ Total number of shrimps stocked) × 100.)

Production of shrimp = (No. of shrimp caught × Average final weight of shrimp) were calculated.

Statistical analysis: The data collected throughout the experimental period were recorded, stored and then analyzed using one-way analysis of variance (ANOVA). Tukey's post hoc test ($p<0.05$) was used (IBM SPSS Statistic 20 software) to identify significant differences among all the treatments. Results were expressed as the mean standard error and the difference was considered significant at $p<0.05$.

Results and Discussion

Growth performance and production, and feed utilization: The use of probiotics in shrimp ponds was considerably ($p<0.05$) beneficial. In comparison to the control treatment, all probiotic-treated treatments showed enhanced growth performance and production (Table 1). The best significant ($p<0.05$) results were obtained by the Miracure product (T_1). In the majority of cases, T_1, T_2, and T_3 produced findings that were similar without significant differences ($p<0.05$). The probiotics application significantly ($p<0.05$) improved feed utilization indices of shrimp in all probiotics-treated ponds compared with the control ponds. Treatment 1 achieved the best FCR values compared with the other treatments. But T_1, T_2 and T_3 gave similar values for FCR without significant differences among them ($p > 0.05$). Treatment 1 reduced FCR values by 38.7% compared with the control, while the reduction percent was 35.6 and 33.5% for T_2 and T_3, respectively. Treatment 1 achieved 39.6% higher values for SGR compared to the control treatment (T_4). Also, T_2 and T_3 obtained 37.5% and 39.8% higher values for SGR, respectively, compared to T_4. Compared to the control treatment, T_1 had a 18% significantly greater survival rate. However, there was no discernible difference in survival between T_2 (15%), and T_3 (14%). Shrimp production was statistically higher in T_1, T_2, and T_3 compared to control (T_4). There was a notable variation in production among the four treatments but variation was not found between T_2 and T_3.

The welfare and performance of farmed organisms are directly impacted by the quality of the aquatic environment (Hura *et al.*, 2018). Probiotics considerably enhanced the growth performance and feed utilization of the tiger shrimp in the current study as compared to the control treatment. The Miracure treatment produced the best outcomes. The positive effects of probiotics treatments are in agreement with many studies in shrimp, *P. monodon* and marine fishes. Shefat (2018) stated that, in aquaculture, probiotics have a substantial effect on the immune system, growth rate, and feed utilization capacity of shrimp, prawns, crabs, and finfish. Pal *et al.* (2010) found that growth and production of

P. monodon in probiotic-treated ponds were superior to those in the control ones. Probiotics are beneficial for shrimp (*P. monodon*) growth and output, but they are essential to determine the right and profitable stocking density, according to Ghosh *et al.* (2013). For marine fishes, Aly *et al.* (2016) noticed that EM® probiotic significantly boosted the final weight and specific growth rate of European seabass fry compared with the control treatment with 26.7% improvement. Additionally, Lotfy (2015) revealed that probiotics to the rearing water of *Sparus aurata* increased ADG by 36.7% when compared to the control. El-Okaby (2015) concluded that *Sparus aurata*, the fingerlings' growth performance, feed consumption, condition variables, and survival percentage were all better in probiotics treated ponds than those of the control. The beneficial role of beneficial microorganisms in improving the digestive system (Thiam *et al.*, 2015; Lotfy, 2015), stimulating appetite, producing vitamins, breaking down indigestible nutrients (Irianto and Austin, 2002), lowering pathogenic microbes in the gastrointestinal tract (Lotfy, 2015), and ultimately improving feed absorption (Tovar *et al.*, 2002) may be the reason for the positive effect of probiotics in improving the nutritional status of fish and shell fish species.

Table 1. Effects of probiotics on growth performance and feed utilization of studied tiger shrimp for 120 days culture.

Species and production parameters	Treatments			
	T_1 (Miracure)	T_2 (Biozyme)	T_3 (Rapid grow)	T_4 (Control)
Average initial weight (g)	0.006 ± 0.001	0.006 ± 0.001	0.006 ± 0.00	0.006±0.001
Average final weight (g)	19.12 ±1.02^{a}	18.90±0.87^{a}	18.25± 1.05^{a}	13.80±1.11^{b}
Daily weight gain (g)	0.16± 0.02^{a}	0.15 ± 0.02^{a}	0.15± 0.01^{a}	0.11±0.01^{b}
Food conversion ratio (%/day)	2.10±0.55^{b}	2.21±0.53^{b}	2.28±0.60^{b}	3.43±0.59^{a}
Specific growth rate (%/day)	7.19±0.18^{a}	7.08±0.19^{a}	7.20±0.17^{a}	5.15±0.10^{b}
Survival rate (%)	78.00 ± 03^{a}	76.00 ± 05^{a}	75.00 ± 04^{a}	66.00±06^{b}
Production (kg/ha)	894.82± 94.69^{a}	861.84 ± 74.81^{a}	821.30 ± 59.31^{ab}	546.48±29.38^{c}

Values are presented as mean ± SD (n=3); means in row bearing different superscript letters differ significantly ($p<0.05$).

The beneficial effects of probiotics of the present work is coincided with many researchers for shell fish, catfish and other species like Pacific white shrimp *Penaeus vannamei* (Xia and Zhu, 2014), Gilthead sea bream *Sparus aurata* (Lotfy, 2015), European sea bass *Dicentrachus labrax* (Aly *et al.*, 2016)), yellow perch *Perca flavescens* (Shaheen *et al.*, 2014), Asian catfish *Pangasius hypophthalmus* (Gobi *et al.*, 2016), Abalone *Haliotis discus hannai* (Guo *et al.*, 2017), tilapia *O. niloticus* (El-Kady *et* *al*., 2022, Madani *et al*., 2018; Sutthi *et al*., 2018; Wang *et al*., 2017; Wang *et al*., 2008b; Zhou *et al*., 2010) and stinging catfish *Heteropneustes fossilis* (Sohel *et al*., 2023) . The FCR and growth performance of *O. niloticus* were significantly improved by *Bacillus subtilis*, *B. licheniformis*, and combination. *Bacillus* species have a dose-dependent capacity to improve growth performance (Elsabagh *et al*., 2018; Madani *et al*., 2018). Shahriar *et al.* (2024) demonstrated that adding commercial probiotics that are readily available in the area to *A. testudineus* diets enhanced resistance, ematobiochemical indices, nonspecific immunity, and growth and feed utilization performance.

Water quality: Application of probiotics as a water additive showed significant (p<0.05) improvement in water quality parameters (Table 2). The values of water transparency and alkalinity of probiotics treated ponds were significantly different from control ponds. The lowest value of ammonia nitrogen (NH_3) was in favor of T_1 (Miracure product). The control treatment exhibited the highest levels of NH_3. The probiotics-treated treatments showed a decreasing ratio in NH_3 values, with rates varying between 51.5–58.6%, compared with the control treatment.

Table 2. Effects of probiotics on water quality parameters of tiger shrimp experimental ponds for 120 days culture.

Parameters	Treatments			
	T_1 (Miracure probiotics)	T_2 (Biozyme probiotics)	T_3 (Rapid grow probiotics)	T_4 (Control)
Temperature (ºC)	29.05 ± 1.83	29.10 ± 1.79	29.12 ± 2.003	31.06±1.98
Water transparency (cm)	28.15 ± 2.55 [a]	28.30 ± 2.71 [a]	28.41± 2.37 [a]	41.66±2.46 [b]
Dissolved oxygen (mg/l)	4.84 ± 0.28	4.79 ± 0.27	4.77 ± 0.28	4.02±0.27
Salinity (ppt)	4.74 ± 0.79	4.66 ± 0.82	4.73 ± 0.77	4.71±0.76
pH	7.54 ± 0.20	7.50 ± 0.20	7.48 ± 0.21	6.65±0.19
Total alkalinity (mg/l)	105.92 ± 3.47 [a]	102.87 ± 3.66 [a]	99.83 ± 3.47 [a]	80.12±3.46 [b]
Ammonia nitrogen (mg/l)	0.041 ± 0.026 [a]	0.045 ± 0.025 [a]	0.048 ± 0.024 [a]	0.099±0.025[b]

Values with a different alphabetical superscripts in the same row differ significantly (*p<0.05*). All values are expressed as mean ± SD (n=3).

According to a number of studies, probiotics improve feed digestion, boost the immune system, and increase growth and survival in aquaculture (Huerta-R´abago *et al*., 2019). The majority of scholars looking into how probiotics affect aquaculture have so far employed nutritional supplements. The possible advantages of administering probiotics in water, however, have received little consideration (Jahangiri and Esteban, 2018). Probiotics have been developed in laboratories, but there are now commercial products on the market. *Bacillus* isolates are among the essential bacterial species present in the majority of commercial products (Martínez Cruz *et al*., 2012). A number of variables, including water temperature, transparency, DO, salinity, pH, alkalinity, ammonia, probiotic source, dosage, inoculation period, and fish/shrimp age, might influence the effectiveness of probiotics administered through water (Jahangiri and Esteban, 2018, El-Kady *et al*., 2022). Water qualities of the treatment ponds of tiger shrimp stayed well in comparison to control ponds (Pal *et al*., 2010).

The current study's results show a significant improvement in water quality, as seen by a notable drop in the levels of harmful ammonia in ponds treated with probiotics. The treated ponds' transparency and alkalinity differed greatly from the control ponds. Such findings are consistent with other earlier research (Balcazar *et al*., 2006; Banerjee and Ray, 2017; Jahangiri and Esteban, 2018; Jozwiakowski *et al*., 2009; Zheng *et al*., 2011; Zhang *et al*., 2011). When the denitrifying bacteria *Bacillus licheniformis* was added to fish rearing water, toxic chemicals (TAN and NH_3) reduced and the rate at which protein and starch in leftover or uneaten feed degraded rose, according to Zheng *et al*. (2011). Wastes were mineralized as a result of *Bacillus* genera' biodegradation process (nitrification and/or denitrification) of nitrogenous by-products, which also improved the quality of the water (Zhang *et al*., 2011).

It has been shown that Bacillus strains are useful for clearing organic materials from aquatic training ponds (Luis-Villase˜nor *et al*., 2011). Zorriehzahra *et al*. (2016) stated that gram-negative bacteria can turn organic materials into bacterial biomass, while gram-positive bacteria-specifically *Bacillus subtilis*-can effectively convert organic matter to carbon dioxide, gram negative bacteria can convert organic matter into bacteria biomass. Probiotics like *Bacillus* sp. added to rearing water would boost beneficial bacteria and proliferate them in fish/shrimp ponds (Kuebutornye *et al*., 2019). Zhu *et al*. (2019) therefore came to the conclusion that within seven days of the bacterial addition, *Melampodium gracile* YL28 absorbed 95.6% of ammonium and eliminated about 99.3-99.96% of nitrite from the water. Ammonia also dropped in ponds treated with probiotics for Nile tilapia (Wang *et al*., 2017) and grass carp *Ctenopharyngodon idellus* (Zhang *et al*., 2011). Regarding the advantages of introducing probiotics to marine environments, Aly *et al*. (2016) obtained that, when compared to the control treatment, the EM® probiotic reduced the amount of TAN and NH_3 in the rearing tanks of European seabass fry, with an ammonia removal efficiency of 66.28%. El-Kady *et al*. (2022) found that probiotic-treated groups, particularly EM®, showed a significant ($p<0.05$) drop in TAN and NH_3 when compared to the control. The control group had higher TAN and NH_3 concentrations. Comparing the probiotic-treated groups to the control group, the ratio of

TAN and NH_3 values decreased, with rates ranging from 43 to 64% and 52.6-32.3%, respectively. Xu *et al*. (2013) reported that *Bacillus* sp. can create extracellular enzymes and antimicrobial peptides that inhibit pathogenic bacteria and enhance water quality, which is another important advantage of adding probiotics to water.

Sediments quality: After the probiotics application, nutrient level in sediments such organic matter, total nitrogen, phosphorus and potassium was significantly decreased (Table 3). The amount of organic matter (OM) in probiotics treated ponds was significantly lower of 31.5-34.7% compared to control ponds. The concentrations of total nitrogen (TN), phosphorus (P) and potassium (K) in treated ponds were significantly decreased ($p<0.05$) than that of control ponds. The decreasing rate of TN, P and K contents in treated ponds were of 25.6-29.6, 58.0-59.1 and 27.8-33.3%, respectively compared to control ponds.

Table 3. Effects of probiotics on sediment qualities of experimental shrimp ponds.

Parameters	Treatments			
	T_1 (Miracure)	T_2 (Biozyme)	T_3 (Rapid grow)	T_4 (Control)
pH	7.88±0.08	7.84±0.07	7.80±0.06	6.18±0.05
Salinity (Ec) (dS/m)	13.26±4.69	13.32±4.84	13.50±5.13	13.52±5.15
Organic matter (%)	1.43±0.16 ^{a}	1.45±0.12 ^{a}	1.50±0.16 ^{a}	2.19 ±0.17 ^{b}
Total nitrogen (%)	0.088±0.008 ^{a}	0.091±0.007 ^{a}	0.093±0.006 ^{a}	0.125±0.005 ^{b}
Phosphorus (μg/g)	8.04±3.36 ^{a}	8.09±2.67 ^{a}	8.12±3.38 ^{a}	11.43±3.35 ^{b}
Potassium (meq/100 g)	0.60±0.04 ^{a}	0.63±0.02 ^{a}	0.65±0.01 ^{a}	0.90±0.01 ^{b}

Values with a different superscripts in the same row are significantly different ($p<0.05$). All values are expressed as mean ± SD (n=3).

By holding onto or releasing nutrients, pond sediment contributes significantly to the cycling of nutrients. The use of probiotic in aquaculture ponds was strongly recommended by Moriarty (1996). In a shrimp farm in West Java, Suhendra *et al*. (1997) found that regular usage of commercial probiotics led to improved environmental conditions, less organic matter accumulation, and better water quality. Following the ponds' treatment with commercial probiotics, the study's data revealed lower quantities of OM, TN, P, and K in the sediment. So, it was determined that the probiotics enhanced the ecology of the shrimp pond and had a significant impact on nutrient cycling.

The lowering of sediment nutrient levels in the shrimp ponds under study was consistent with a prior study that found that probiotic additions significantly ($p<0.05$) reduced the levels of total organic carbon (TOC), total nitrogen, phosphorus, and total inorganic phosphorus (TIP) in the sediment (Matias *et al.*, 2002; Wang *et al.*, 2005; Wang and He, 2009). Boyd *et al*. (1994) and NACA (1995) stated that soil conditions are more crucial than water conditions in influencing brackish water productivity. Similarly, Chakrabarti *et al*. (1985) suggested that, just as temperature and salinity in the water phase affect shrimp production, organic carbon, available nitrogen, and phosphorus in the soil phase also have a direct relationship with shrimp production.

Bacterial load: The quantitative load of total heterotrophic bacteria (THB) increased and simultaneously the quantity of *Vibrio* sp. decreased in all probiotics treated compared to without probiotic ponds (control). The bacterial population varied with each sampling, consistently showing higher levels in sediment compared to water in both ponds treated with probiotics and control ponds (Figs 1-4). By the end of the culture period, bacterial populations increased in the probiotic-treated ponds. The proportion of *Vibrio* spp. relative to the THB in the control ponds did not exhibit a significant decline. *Vibrio* spp. contributed substantially to the THB load in the control ponds, whereas the probiotic-treated ponds demonstrated a lower abundance of *Vibrio* spp. The outcomes of this study are close to Dalmin *et al*., 2001; Pal *et al*. (2010) and Islam *et al*. (2013). The current

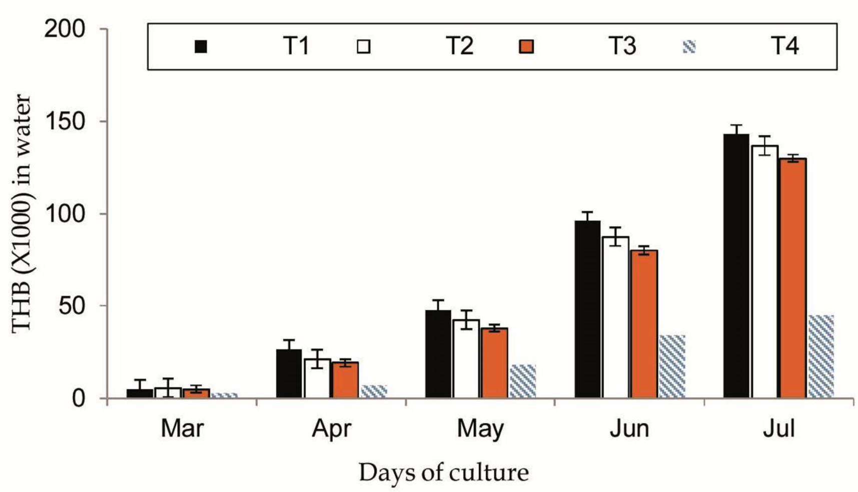

Fig. 1. Quantity of THB in shrimp ponds water with and without probiotics in different treatments.

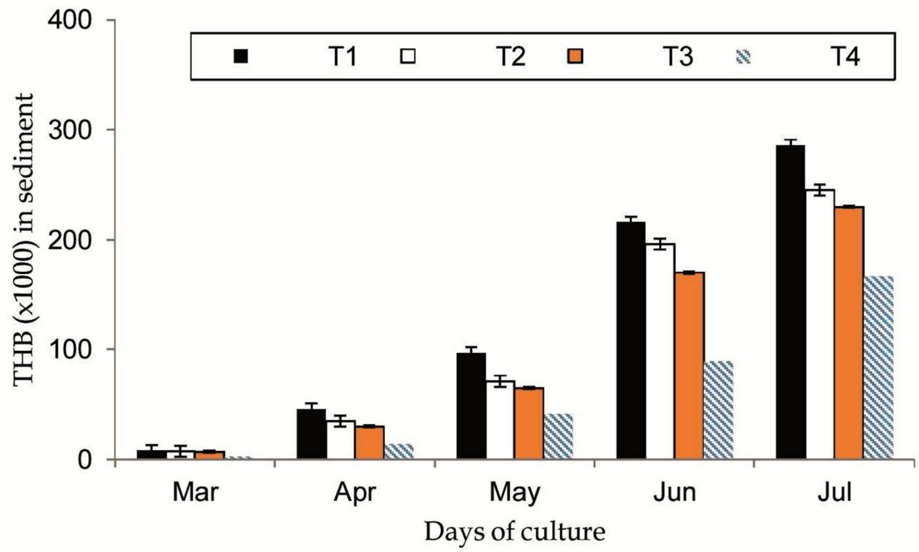

Fig. 2. Quantity of THB in shrimp ponds sediment with and without probiotics in different treatments.

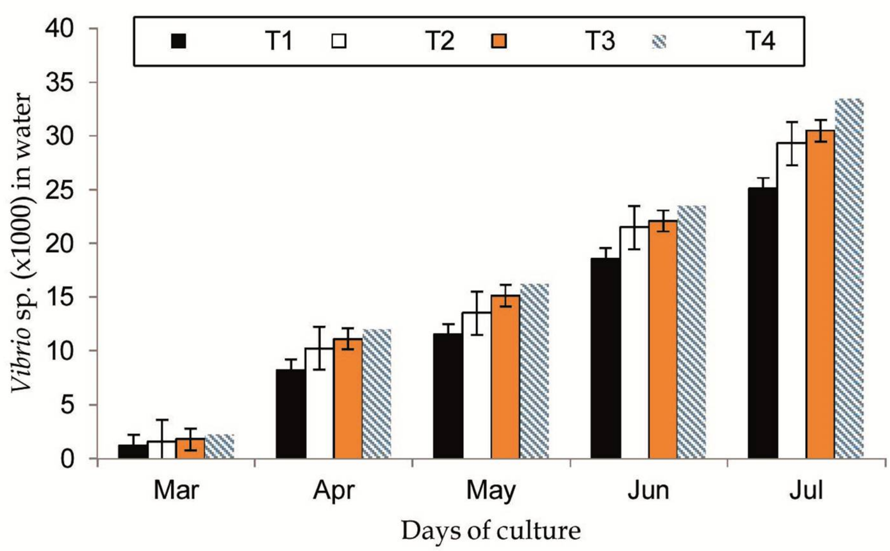

Fig. 3. Quantity of *Vibrio* sp. in shrimp ponds water with and without probiotics in different treatments.

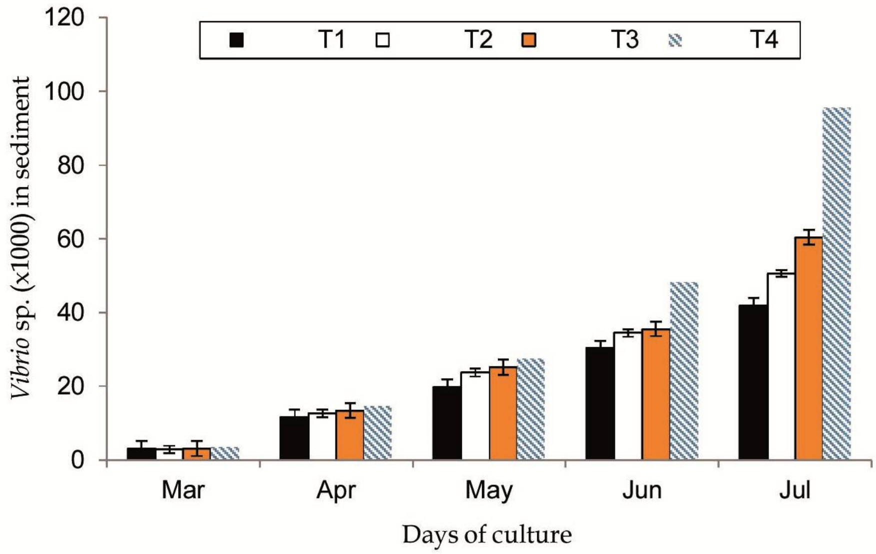

Fig. 4. Quantity of *Vibrio* sp. in shrimp ponds sediment with and without probiotics in different treatments.

probiotic study is associated with better shrimp growth, water quality, and fewer pathogenic microorganisms. Because of the actions of autochthonous flora such as *Flavobacterium*, *Micrococcus*, and *Alcaligenes* that are present in the ecosystem, the probiotic's 10^{10} CFU/ml *Bacillus* spp. number dropped to 10^{3} CFU/ml after being applied in the pond. The vibrios' burden also significantly decreased at the same time (Westerdahl *et al*., 1991).

Conclusion

The effectiveness of commercial probiotics as an additive to shrimp growth and to enhance the quality of water and sediment varies greatly. The application of small amounts of commercial probiotics in shrimp ponds produced numerous positive results, including an increase in growth performance of 32.2-38.5%, a decrease in FCR of 33.5-38.7%, an improvement in survival rate of 14-18%, and a reduction in the ammonia content in rearing water of 51.5-58.6%. The application of probiotics significantly reduced the amount of nutrients in pond sediment such as OM by 31.5-34.7%, TN 25.6-29.6%, P 58.0-59.1%, and K 27.8-33.3%, which were utilized to boost shrimp growth and improve the water quality. The findings indicate the superiority of Miracure over Rapid grow and Biozyme. The use of commercial probiotics increased the amount of

THB and decreased the amount of *Vibrio* sp. Overall, the study supports the importance of probiotics as a water additive to enhance shrimp growth performance, water and sediment quality, though further research is still required to optimize commercial products and apply them properly, which will improve the aquatic environment for shrimp farming and production in ponds.

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INDUSTRIAL FIRES IN BANGLADESH AND PATHWAYS TO PREVENTION

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Abstract

Fire hazards have become increasingly prevalent in the industrial sector of Bangladesh due to the rapid expansion of unregulated industries, inadequate infrastructure, and poor safety standards for complex machinery and strenuous processes. Export-oriented garment industries maintain some safety standards due to buyer organizations, trade unions, and government requirements, while other sectors still face significant risk, causing substantial economic and human losses. This study investigated the causes, impacts, and gaps in the existing systems that contribute to industrial fire risks by employing a qualitative method, involving the analysis of incident reports and key informant interviews (KII) with fire safety experts and first responders. Findings revealed that inadequate fire protection systems, noncompliance with safety regulations, and a lack of effective preventive strategies are mainly responsible for fire hazards in the industrial sector. Outcomes are supported by case studies, demonstrating that these deficiencies led to significant losses of life, property, and economy. This study identified several critical prevention measures, including hazard analysis, employee training, safety drills, safety inspections, emergency action plans, infrastructure planning, and emergency evacuation plans to safeguard lives, assets, and businesses. The findings emphasise the need for a comprehensive, policy-driven strategy to mitigate fire hazard risk across diverse industries in Bangladesh.

Key words: Fire; Industrial Fire; Hazard; Fire Mitigation; Preventive Measures

Introduction

Bangladesh has recently progressed from a low-income to a middle-income country, with economic advancement largely driven by its industrial sector. The country's industrial sector, including the ready-made garments, polymers, medicinal products, and plastic industries, has developed a lot during the past few years (Wadud and Huda, 2017). This sector's contribution to the nation's GDP was 32.45 per cent in 2015-16, which increased

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to 37.65 per cent in 2022-23, as stated by the Bangladesh Bureau of Statistics (Bangladesh Economic Review, 2024). Among all sectors, the textile sector alone contributes 13% to GDP growth and 75% of foreign currency earnings in Bangladesh (Firoz, 2011). According to the Bangladesh Garment Manufacturers and Exporters Association (BGMEA) (2022), the garment industry, as the leading export segment of Bangladesh, generated around US$27.9 billion in 2019–20 (Islam *et al.*, 2022). Despite the growing contribution of the industrial sector to the economy, its rapid development without adherence to proper construction guidelines has led to increased workplace safety concerns, particularly regarding fire hazards (Wadud and Huda, 2017; Islam *et al.*, 2022; Azad *et al.*, 2018). In 2020, of 383 industrial fires in Bangladesh, 273 occurred in the ready-made garment sector (Ekramuzzaman, 2024). However, the issue of worker safety has gained attention due to two major catastrophes, the Tazreen fire and the Rana Plaza collapse, demanding proper responses from all stakeholders. The catastrophic events in Bangladesh led to the establishment of various systems of management intended to enhance safety in the nation's textile sector during fires or other emergencies (Mizanuzzaman, 2016). While the export-oriented garment industry has a relatively good working environment, partly due to the special attention of various buyer groups, trade unions, and the government, the working environment in other industries is unsatisfactory (Alam, 2006; Ahmed and Hossain, 2009).

The human cost of these deficiencies is alarming and massive. In 2024, 758 workers died in 639 workplace accidents across the country, according to a survey conducted by the Safety and Rights Society (SRS) (Safety and Rights Society, 2024). The fire-related hazard alone constitutes a significant fraction of these fatalities. Islam *et al.* (2022) assessed over 237 incidents to determine the causes and number of casualties in industrial zones and found that 94.09% were attributable to fire incidents. Statistics from the Fire Service and Civil Defense (FSCD) indicate that 6,081 fire incidents occurred in industrial establishments over six years, from 2015 to 2020, which caused an estimated financial loss of around 372 crore BDT (Share Biz News, 2021). The lives of many workers are endangered by fire risks; many have already lost their lives. The FSCD annual statistics indicate that between 2021 and 2024, 3,561 fire incidents occurred in industrial establishments (Fig. 1(a)). These incidents resulted in 242 injuries and 249 fatalities (Fig. 2), highlighting a significant human toll. Moreover, the estimated property loss resulting from these incidents amounted to approximately 4,611 million Bangladeshi Taka (Fig. 1(b)), emphasizing the substantial economic consequences of industrial fire hazards (FSCD, 2021–2024). Moreover, these fire incidents might also lead to significant structural failures (Stochino *et al.*, 2024).

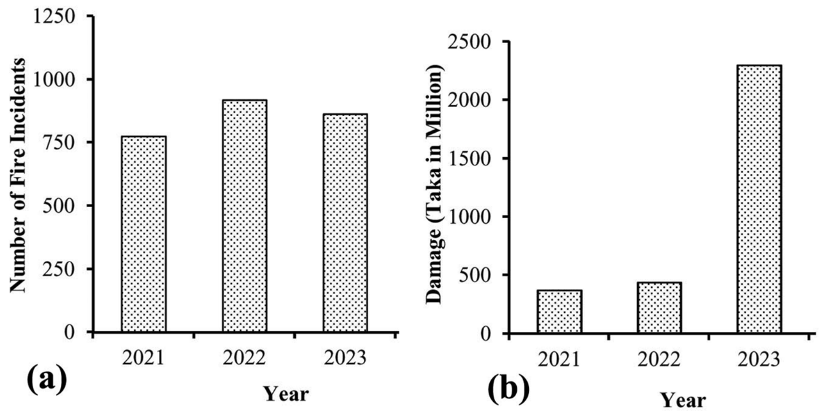

Fig. 1(a) Incident Count and (b) Damage Chart.

Even though garment factories have higher safety standards than other industries, a significant number of fire accidents still happen in this sector alone (Azad *et al.*, 2018). In 2024, BGMEA catalogued 4,149 garment factories (BGMEA, 2024), employing approximately 4.1 million people (Karim, 2020). According to the BGMEA, these factories experienced 206 fire accidents, resulting in approximately 300 fatalities between 1991 and 2011 (Mahabub, 2013).

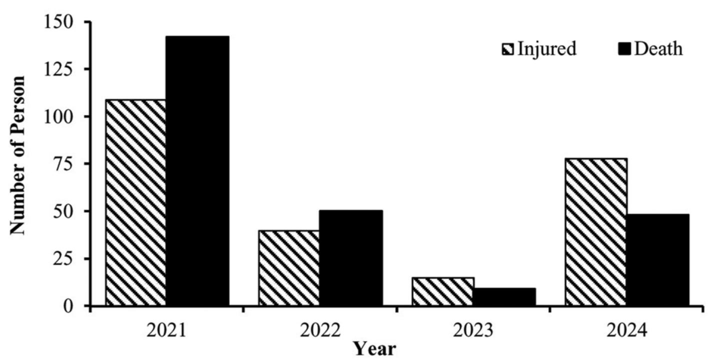

Fig. 2 Death and Injuries due to Industrial Fire Hazards.

Several researchers have identified the causes of fire occurrences in numerous studies. While electric short circuits and boiler explosions are identified as the main causes of fire hazards; insufficient emergency exit routes and staircases, suffocation due to smoke, lack of properly marked exits, absence of underwater reservoirs, ineffective fire control systems, lack of emergency lights, and insufficient fire extinguishers further exacerbated the situation and enhanced the casualty rate (Azad *et al.*, 2018; Islam *et al.*, 2022; Chowdhury *et al.*, 2025). Over 90% of the industry lacks a fire control training system, just 5% of workers have received first aid training, and over 50% of workers are unaware of how to protect themselves from fire disasters (Azad *et al.*, 2018). Islam and Hossain (2018) reported that before fire hazards, only 34.7% remain alert, 7.9% take preparatory measures, and 1.0% attempt to learn about the fire management system, while 56.4% have no minimum fire mitigation measures. During incidents, 52.5% contact the fire service, 22.8% try to use water, 7% collaborate with the fire management team, and 15.8% are unaware of what to do.

In Bangladesh, few studies have investigated the causes, risks, losses and damages, fatalities, impacts, existing mitigation strategies, and response initiatives related to fire hazards in the industrial sector, especially in the readymade garments sector. For instance, Azad *et al.* (2018) examined the causes and effects of fire catastrophes across 20 industries in Gazipur, Dhaka, and tried to identify the best course of steps to reduce their impact. Wadud and Huda (2017) evaluated the fire risk in Dhaka's ready-made garment factory, revealing a mean Fire Risk Index (FRI) of 2.8 on a scale of 5.0, a highly alarming indicator. The findings also revealed that, among the 24 parameters assessed, locked exit doors, lack of emergency announcement system, and inadequate fire drills worsen the fire scenario. Mizanuzzaman (2016) assessed the losses and damages caused by fire hazards in selected garment factories in Bangladesh, demonstrating that fires result in substantial economic losses and damages within this industry. Ekramuzzaman (2024) evaluated the socio-economic consequences of fire incidents in ready-made garment factories, concluding that recurrent fires have resulted in fatalities, labour unrest, economic and reputational damage, job losses, and a decline in foreign investment in Bangladesh. To the best of our knowledge, no research has yet developed and proposed a specific, suitable, and actionable preventive strategy to mitigate fire hazards in the industrial environments of Bangladesh. However, certain academics are currently focusing on developing effective fire prevention measures for the industrial sector in other parts of the world (Wong and Xie, 2014). Since fire hazards are causing factories to be damaged, economies to be collapsed, and lives to be lost in Bangladesh (Figs. 1 and 2), a comprehensive investigation into the causes of fires, a timely and realistic plan, actionable occupational safety measures, and prevention strategies are required to reduce the risk of fire hazard and maintain the development trend of the industry.

To address research gaps and strengthen the industrial sector's resistance to fire hazards, this study used a qualitative methodology grounded in key informant interviews (KII) with fire safety experts, first responders, and policy specialists to identify the potential causes of fire hazards, evaluate the shortcomings of mitigation strategies, determine the difficulties encountered during evacuation efforts, and investigate the crucial elements of industrial fire prevention. Finally, the study outlined actionable preventive strategies to minimise the risk of industrial fires, ensure safe evacuation, and an appropriate response in the event of an emergency. The results highlight the importance of developing and implementing occupational safety programs in industrial sectors. The results will guide policymakers in improving relevant policies, strengthening safety infrastructure, protecting personnel's lives, and reducing property and economic losses.

Methodology

This study employed a qualitative research method, involving document reviews and KII to collect information on the causes of fire, existing mitigation approaches, and efficient prevention strategies to reduce fire risks in the industrial sector of Bangladesh. This work analysed the overall condition of the industrial sector in Bangladesh, focusing on fire safety across various sectors rather than a specific industrial zone. Therefore, the preventive strategies suggested in this study are suitable for all industrial sectors across the country.

Document review: The initial exploratory phase of this study involved a comprehensive investigation of incident reports, newspaper articles, governmental reports, statistics of FSCD, reports of BGMEA, and various other relevant organizational reports to determine the original problem, detect the causes, comprehend present practices and existing mitigation procedures, evaluate safety protocols, and pinpoint deficits in the existing fire hazard prevention system in the industrial sector of Bangladesh.

A crucial part of this document review involved a comprehensive study of seven official fire investigation reports from the FSCD, each describing notable industrial fire events. The selected events are based on the criteria of severity, relevance, and their accessibility, including Hashem Foods Ltd. (2022); Green Cozy Cottage, Bailey Road (2024); Tampaco Foils Ltd., Tongi, Gazipur (2016); Tazreen Fashions (2013); Zaman Jute Mill, Khulna (2024); Jahin Knitwear, Narayanganj (2022); and Square Pharmaceuticals Ltd., Gazipur (2022). All of the incidents investigated fall under different industrial sectors, as outlined in the Bangladesh Industrial Policy 2022: readymade garments, pharmaceuticals, agricultural and food processing, jute-based production (Annexe I), printing and packaging (Annexe II), and hotels and restaurants (Annexe V) (Bangladesh Industrial Policy, 2022). Each report examined was produced by the FSCD investigative committees, formed after major fires in various sectors. These reports investigate the specific causes of the fires, evaluate the resulting damage, and propose measures to prevent similar events in the future. This method ensured the incorporation of fire safety issues and preventive recommendations from industries of all sizes and types.

The collective examination of these reports forms the basis for the next stage, KII, enabling the formation of in-depth questionnaires that captures all relevant issues.

KII: Although the assessments of prevailing literatures offered preliminary information into the existing issues and current practices, a more profound and specialized understanding was essential to meet the objectives of this study. Therefore, KII were conducted in this study to gather specialised insights from experts in this field. The key informant analysis offers access to expert knowledge, captures the unique characteristics and context of the subject, and can reveal hidden or sensitive issues that other methodologies might miss. This inclusive and detailed information provide a comprehensive understanding of the problem.

Participants comprised senior officials from the FSCD, safety officers, first responders to fire incidents, industrial zone managers, and policy experts specialising in workplace safety and disaster risk mitigation (Fig. 3). Each participant was selected based on a purposive or judgmental sampling technique, a non-probability sampling procedure employed in qualitative studies. Participants were deliberately selected by the researcher based on their knowledge, proficiency, skills, and experience in fire hazards, industrial safety management, and fire risk mitigation. Semi-structured interviews were conducted using pre-developed questionnaires that addressed the causes, risk perception, existing mitigation practices, implementation problems, and efficient preventive measures regarding fire hazards and the occupational safety of workers in the industrial sector. Interviews were conducted either in person or via digital platforms, consent was obtained from respondents prior to recording, and information was organised for thematic analysis.

Data Analysis: Finally, the findings from the document reviews and KII were systematically documented and thematically evaluated to detect potential reasons, structural susceptibilities, mitigation approaches, emergency preparedness, institutional deficits, and preventive procedures to mitigate the risks associated with industrial fire hazards and diminish the loss of life, property, and the economy in the upcoming events. Thematic analysis of relevant literature and interviews enabled the integration of insights from multiple sources, resulting in a comprehensive understanding of fire risks and the development of appropriate preventive measures to mitigate them in the industrial sector of Bangladesh.

Fig. 3. Key Informant Interview (KII) with Fire Service and Civil Defense officials.

Data Analysis: Finally, the findings from the document reviews and KII were systematically documented and thematically evaluated to detect potential reasons, structural susceptibilities, mitigation approaches, emergency preparedness, institutional deficits, and preventive procedures to mitigate the risks associated with industrial fire hazards and diminish the loss of life, property, and the economy in the upcoming events. Thematic analysis of relevant literature and interviews enabled the integration of insights from multiple sources, resulting in a comprehensive understanding of fire risks and the development of appropriate preventive measures to mitigate them in the industrial sector of Bangladesh.

The aforementioned technique has been instrumental in efficiently understanding fire safety concerns, with satisfactory results in other studies (Owusu-Sekyere *et al.,* 2017). Hence, this technique was utilised in this study to identify root causes and develop preventive strategies to mitigate the risks of fire hazards and the associated loss of life, property, and the economy.

Results and Discussion

The main objective of this study was to develop effective prevention strategies to impede or mitigate industrial fire risks. Before developing preventive measures, it is essential to identify the underlying causes of fire accidents in industrial sectors. For this purpose, the study reviewed relevant documents, newspapers, and reports from relevant governmental organisations on fire incidents, and conducted KII with industrial zone managers, fire safety officials, policy specialists, and first responders to fire incidents. Through this process, the causes, current mitigation measures and systems, implementation difficulties, emergency response, and recommended prevention practices were identified. The findings are briefly described below.

Causes of Fire Hazards in Industries

Fire prevention practices have improved in export-oriented garment factories; however, significant fire hazards persist in other industrial facilities. Industrial fires will continue if they're not addressed properly. The first step toward effective fire prevention is a comprehensive understanding of the specific hazards within a facility and the dominant causes of fire risks in industrial settings. A successful fire prevention program involves more than merely identifying risks; it requires an integrated strategy to address these hazards on multiple levels. The main causes of fire hazards are outlined below:

Non-compliant Industries: At present, buildings are not being constructed in compliance with the country's fire safety codes. Additionally, the owners are constructing buildings by violating rules and norms to maximise profits, without protecting the occupational safety and health environment of the industrial facility. Moreover, it is alleged that most developed industries lack regulations. All these issues are exacerbating fire risks in the industry, potentially resulting in significant damage to property, economy, and human life (Hideki, 2015; Azad *et al.,* 2018).

Unplanned Infrastructure: The materials utilized in constructing buildings and the products generated within the structure significantly influence the spread and intensity of fire. Unfortunately, in Bangladesh, construction codes are violated, and structures are often used for unintended purposes. This leads to an increase in fire incidents, which in turn increases the number of casualties. For example, in July 2021, a fire at the Hasem Food factory in Narayanganj resulted in the deaths of 52 individuals (Prothom Alo, 2021). Investigation revealed that the factory was built without permission. Furthermore, sufficient and appropriate fire safety measures were absent, which exacerbated the impact of the incident.

Lack of Necessary fire Protection Systems and Equipment: Fire safety measures are inadequate across industries outside Bangladesh's sole garment industry. In most cases, the structure lacks a sufficient and necessary firefighting system. This finding was also demonstrated in an earlier study conducted by Ahmad and Kamruzzaman (2015). However, in several locations, firefighting equipment was discovered, but it was predominantly outdated. This is corroborated by a study of Tabassum *et al.* (2014), demonstrating that while most of the industry had some firefighting apparatus, it was not properly maintained. The lack of appropriate, sufficient, and modern firefighting systems exacerbates fire hazards in Bangladesh's industrial sector.

Storage of Dangerous Goods, Flammable and Combustible Materials: Factories utilize various combustible materials, including chemicals, liquids, solids, and gases that are easily ignitable. Fire may occur if these flammable materials are not stored properly. Sometimes combustible materials are stored in the factory with permission to operate as a warehouse, which may cause a fire if not stored properly. For example, the devastating fire at the BM depot in 2022 (Fig. 4(a)) resulted in more than 40 fatalities and 200 injuries (Chowdhury, 2023). The investigation disclosed that the presence of hydrogen peroxide in the depot and the failure to comply with appropriate safety protocols resulted in the incident.

Smoking Precautions: According to the FSCD's 2023 annual statistics, there were 4906 fire incidents in the country caused by burning bits of cigarettes. This was also the second-highest leading cause of fire in 2023 (FSCD, 2023). Therefore, precautions should be taken when smoking to prevent factory fires. If necessary, smoking should be completely prohibited in the critical establishment, or separate rooms should be arranged for smoking.

Chemicals and Fuels: Chemicals and fuels are utilized in industrial plants. However, industries lack skilled and experienced manpower when using them, which causes accidents such as fires. Therefore, experienced personnel must be engaged in the management and use of chemicals and fuels to reduce fire hazards. Moreover, appropriate regulations must be followed in storing chemicals and fuels. Chemicals must be stored in a designated room at a specific temperature to mitigate fire hazards. Improper management of chemicals and fuels may lead to significant fire incidents. For example, 71 people lost their lives in a terrible fire event at the chemical warehouse (categorized as industry according to Annex V of the Bangladesh Industrial Policy 2022) at Churihatta intersection in Chawkbazar on 20 February 2019 (Fig. 4(b)) (Prothom Alo, 2022; Bangladesh Industrial Policy, 2022). The investigation revealed noncompliance with proper chemical storage regulations at that site, which caused the fire.

Electrical Faults: Overloaded circuits, defective wiring, substandard electrical appliances, and improper use of electrical equipment can all cause sparks and ignite adjacent materials. Numerous studies corroborate these conclusions, showing that electrical short circuits are the primary source of fire hazards in Bangladesh's industrial sector (Firoz, 2011).

Fig. 4. (a) Fire Accident in BM Depot Chittagong and (b) Churihatta Chemical Fire Disaster

Spontaneous Combustion: Certain substances, such as oil-soaked rags or improperly stored organic materials, can undergo a heat fermentation process and ignite spontaneously, without external ignition sources.

Welding and Cutting Operations: Welding and cutting operations involve the use of intense heat sources, sometimes referred to as hot work, which generate significant heat that can ignite surrounding combustibles or flammables.

Dust Explosions: Fine, ignitable dust particles suspended in the air can form explosive mixtures when ignited by a spark, causing a fire.

Gas Explosions: Fires are also caused by gas explosions resulting from gas leaks in pipelines or cylinders, insufficient ventilation, malfunctioning equipment, inadequate maintenance, or igniting sources such as sparks, flames, or overheated instruments.

Case Study

A thorough case study of a few industrial fire incidents has been carried out following the identification of the causes of fire in the industrial sector of Bangladesh, including Hashem Foods Ltd, Rupganj, Narayanganj (2021); Green Cozy Cottage, Bailey Road, Dhaka (2024); Tampaco Foils Ltd., Tongi, Gazipur (2016); and Square Pharmaceuticals Ltd., Kaliakair, Gazipur (2022). This study outlines the causes of fire occurrences, identifies shortcomings in fire hazard prevention within the industry, emphasises the need for robust fire protection measures, and provides recommendations to improve the existing system to manage similar events more effectively in the future.

Case Study-1: Hashem Foods Ltd, Rupganj, Narayanganj (2021)

Causes and consequences: On 9 July 2021, at approximately 5 PM, a fire broke out at the multi-story building of Shezan Juice Factory, a part of Hashem Foods Ltd in Rupganj, Narayanganj (Fig. 5(a)). The incident caused over 52 fatalities, missing of many workers, and more than 50 injuries, as many people jumped from the building (Prothom Alo, 2021; Dhaka Tribune, 2021a). The existence of combustible chemicals, plastics, foil, paper, resin, cardboard, and cooking oil intensified the fire. Casualties were enhanced due to deficient fire protection systems and insufficient exit routes. The factory facility, measuring 35,000 square feet, required four to five emergency exits but had only two, both of which were rendered dysfunctional during the fire. The front gate, the sole entry and exit point, was also closed after the fire began, hindering escape and contributing to fatalities (Dhaka Tribune, 2021a). Furthermore, the building was built without governmental permission (Anam, 2022).

After the event, the FSCD developed a five-member investigative committee on 11 July 2021. The inquiry revealed that the fire originated from an electrical malfunction, resulting in property damage equivalent to BDT 2,47,73,25,253 (FSCD, 2022a). The examination carried out by the Narayanganj district administration inquiry committee found that an electrical short circuit in the ground-floor compressor room originated the fire, which spread swiftly due to the presence of excessive amounts of chemicals and foil sheets. The committee revealed insufficient emergency exits and violations of the building code in the facility (Dhaka Tribune, 2021b). Despite the intensity of the fire, the FSCD's quick response and effective firefighting tactics successfully controlled it and prevented its spread to connecting facilities.

Lessons learned: This fire incident highlighted the necessity for automated smoke detection and fire sprinkler systems in industrial buildings. The factory fire underscored the need for fire-resistant materials and effective compartmentalization in large structures. This incident demonstrated the critical need for rapid response, fire safety protocols, adequate fire protection, and effective firefighting equipment in managing fire events and related emergencies. This case study also underscores the necessity for careful storage and maintenance of combustible goods and materials to prevent similar fire threats in the future.

Case Study-2: Fire Incident at Green Cozy Cottage, Bailey Road, Dhaka (2024)

Causes and consequences: The Green Cozy Cottage, a prominent multi-story restaurant located on Bailey Road in Dhaka, experienced a fire on 29 February 2024, resulting in significant casualties and property damage (Fig. 5(b)). After the fire, the FSCD's five-member investigative team reported that the fire originated from an electric kettle at the 'Cha Chumuk' coffee shop adjacent to the ground-floor stairway. Flammable materials near the kettle, the ignition of adjacent items, and a gas leak enhanced the fire's spread, which was further exacerbated by an explosion of the refrigerator compressor. Smoke, heat, and flames rapidly engulfed the stairwell, hindering residents' evacuation through the only staircase (FSCD, 2024). The FSCD study concluded that the building was deficient in essential firefighting systems, lacked an alternate fire escape, contained a narrow, non-compliant stairway, and did not have an appropriate fire safety plan.

Fig. 5. (a) Fire Accident in Shezan Juice Factory, (b) Fire Accident in Green Cozy Cottage, (c) Fire Accident in Tampaco Foils Ltd. Factory, and (d) Fire Accident in Square Pharmaceuticals Ltd. Factory.

The consequences were catastrophic; over 46 people lost their lives due to smoke inhalation and entrapment, while more than 75 experienced injuries (Prothom Alo, 2024). The building experienced significant structural damage, rendering many floors inoperable, and the restaurant was forced to shut down indefinitely. The incident sparked public outrage, led to protests, extensive media coverage, and further demands for stricter enforcement of fire safety standards in commercial establishments across Dhaka.

Lessons learned: The tragic event highlighted significant deficiencies in urban fire safety, especially in densely populated commercial zones. Regulatory deficiencies, including inadequate gas system maintenance, unsafe construction modifications, missing inspections, and a lack of fire escapes, intensified the risk. There was widespread panic because neither staff nor customers were trained in emergency evacuation procedures. Despite the availability of fire extinguishers, they remained mostly unutilized due to inaccessibility and inadequate preparedness. The tragedy emphasizes the necessity of retrofitting older buildings, installing sprinklers, enforcing occupancy restrictions, ensuring accessible exits, and improving coordinated emergency response, which was hindered by traffic congestion, narrow roadways, and poor communication with fire services.

The Green Cozy Cottage fire is an evident reminder that in high-density urban areas, primarily where restaurants and entertainment venues operate, proactive fire safety measures are essential. It calls for comprehensive regulatory reforms, regular audits, improved public awareness, and stronger collaboration between private businesses and public safety agencies.

Case Study-3: Fire Incident at Tampaco Foils Ltd., Tongi, Gazipur (2016)

Causes and consequences: On the early morning of 10 September 2016, a massive explosion followed by a devastating fire broke out at the Tampaco Foils Ltd. factory located in the BSCIC industrial zone of Tongi, Gazipur (Fig. 5(c)). The explosion occurred at about 6:00 AM when the morning shift started. The explosion was so powerful that it caused portions of the five-story building to collapse instantly, trapping numerous workers under the debris (The Daily Star, 2016). The FSCD reported that the fire was finally extinguished on 11 October 2016, following over a month of relentless firefighting efforts.

Primary inquiries suggested that the explosion resulted from a gas leak originating from either the boiler or the gas pipeline system. Significant amounts of combustible chemicals and packaging materials, such as aluminium foil and plastic laminates, exacerbated the fire. The building collapsed due to its inadequate structural integrity, lack of adequate safety engineering, and negligence of prior safety warnings.

A seven-member investigation committee formed by the FSCD submitted a detailed report on the incident. The report stated, "Most of the individuals who gave testimony acknowledged the presence of a gas leak, and it was revealed that Line Supervisor Mr. Subhash went to repair the leak just as the explosion occurred. Based on this, the investigation committee concluded that the explosion was likely triggered by either the pressure of accumulated leaked gas or a spark from an unidentified source igniting the gas. Furthermore, the presence of highly flammable and volatile chemicals stored inside the building contributed to the rapid spread of the fire and caused a secondary explosion throughout the factory (National Human Rights Commission, 2016)." The results indicated both operational negligence and insufficient safety measures as the contributing factors to the disaster.

The human and economic costs of the fire were substantial. At least 40 people were confirmed dead, and 44 people were injured (DIFE, 2016). A significant number of victims were laborers, including adolescents and contract workers, leading in several families losing their sole breadwinners. The facility was completely destroyed, adjacent structures sustained damage, and industrial operations in the vicinity were interrupted, revealing substantial deficiencies in labour protection and industrial safety regulations in Bangladesh.

Lessons learned: This accident exposed significant shortcomings in industrial safety standards, including insufficient emergency training, poor gas pipeline maintenance, blocked or inadequate exits, and a lack of operational fire detection and suppression systems. It also underscored the urgent need for stronger building code enforcement, regular safety audits, and greater accountability for factory owners who disregard their compliance obligations. Moreover, the incident highlighted the importance of strengthening coordination among regulatory bodies, local administration, and emergency services to ensure swift and effective response during industrial accidents.

Case Study-4: Fire Incident at Square Pharmaceuticals Ltd., Kaliakair, Gazipur (2022)

Causes and consequences: On 23 May 2022, a significant fire broke out at the Square Pharmaceuticals Ltd. facility in Kaliakair, Gazipur (Fig. 5(d)). The fire led to an extensive emergency response, with 19 units of the Fire Service working relentlessly for seven hours to bring the flames under control (bdnews24.com, 2022). Following the incident, on 2 July 2022, the FSCD formed a five-member committee to inspect the event. The committee reported that the fire resulted from an electrical malfunction (FSCD, 2022b) and found no evidence of inappropriate conduct. The inquiry revealed significant fire safety deficiencies: the facility lacked an FSCD-approved fire safety plan, sufficient trained personnel for emergency response, and a functioning fire hydrant system. The fire damaged saline, tablet raw materials, and chemicals stored in the affected unit, resulting in significant production losses. The company disclosed to the stock exchange and in its audited financial statements that the incident resulted in an estimated revenue impact of about Tk 50 crore (BDT 500 million) and a profit impact of Tk 8 crore (BDT 80 million) (The Business Standard, 2022; The Financial Express, 2022).

Lessons learned: The committee strongly recommended the fast development and implementation of a comprehensive fire safety plan, along with regular staff training and maintenance of fire suppression systems to prevent similar occurrences in the future. In addition, the event highlights the necessity of routine inspection, repair, and renovation of electrical systems in medical facilities to prevent sources of ignition.

Recommended Practices

This study identified several preventive strategies and practices to mitigate fire hazards in industrial environments, based on case studies, documents, and news articles on fire incidents, as well as KII with fire safety officials, industry managers, and first responders. These strategies and practices will work as actionable guidelines for policymakers, safety managers, and stakeholders. The following outlines recommended strategies and practices for effectively mitigating or controlling industrial fires.

Hazard Identification and Risk Analysis: Industries must regularly conduct routine inspections to identify potential fire risks within the facility and evaluate fire risks across all operational areas. This includes the identification of combustible materials, equipment used, procedures, material storage practices, faulty electrical systems, and improper waste disposal. Such examinations must be carried out in accordance with the National Fire Protection Association (NFPA) and the Department of Inspection for Factories and Establishments (DIFE) guidelines to ensure compliance with standards (NFPA, 2021; DIFE, 2023).

Safe Work Practices and Housekeeping: It is essential to develop, implement, and enforce safe work practices to reduce the use of ignitable materials, guarantee proper handling and storing of combustibles, and maintain a clean and orderly work environment. This must also include separate smoking zones, suitable signage, and appropriate waste-disposal procedures. Strong housekeeping practices are crucial in mitigating or preventing workplace fire incidents.

Employee Training and Drills: It is crucial to develop and implement a training program to provide staff with the information and skills necessary for fire prevention. Training must incorporate fire safety protocols, the effective use of fire extinguishers, the operation of fire alarms, and safe evacuation techniques. Routine evacuation drills must be conducted to ensure personnel are familiar with emergency protocols and can respond effectively and evacuate the workplace safely in the event of a fire emergency. This practice was also recommended in a previous study conducted by Azad *et al*. (2018).

The DIFE mandates the Safety Committee to conduct training for a diverse group of employees, including managers, supervisors, maintenance personnel, emergency managers, first aid responders, evacuation teams, firefighting teams, security guards, and workers. It recommends a yearly training plan and states that this training must be free of charge, conducted regularly, and participation should be regarded as working hours (DIFE, 2023). The Occupational Safety and Health Administration (OSHA) also mandates that all industry personnel must be familiar with fire extinguishers and undergo this training annually. This training also seeks to familiarise workers with the PASS system (Pull, Aim, Squeeze, Sweep) for initial firefighting efforts with fire extinguishers. Local fire departments can assist with this training (OSHA, 2020a).

Fire Protection Systems: It is crucial to install and maintain appropriate fire protection systems. Industrial facilities must install smoke detectors, heat detectors, and fire alarm systems throughout the premises to ensure early detection of fire events. Previous investigations support this suggestion as well (Bukowski *et al.*, 2003; Ko *et al.*, 2009). The facility must be equipped with appropriate fire suppression apparatus, including automatic sprinkler systems, portable fire extinguishers, and fire blankets, ensuring they are easily accessible, regularly maintained, and available for employee use. The fire protection system installed must be tailored to the specific hazards present in the facility and comply with NFPA and OSHA standards (NFPA, 2021; OSHA, 2020b).

Equipment Maintenance: Industrial facilities should regularly examine and service their electrical systems, heating units, machinery, and other potentially fire-prone equipment to prevent malfunctions. Furthermore, fire safety equipment should be inspected regularly to ensure proper working order and preparedness for emergencies. Regular inspection and monitoring of equipment are also critical to ensure that firefighting apparatus are functioning and accessible for emergency response. These inspections should be documented properly for accountability.

Designate Proper Evacuation Routes: Develop and mark all emergency exits, and ensure they are not blocked in any way. Previous research by Nagai *et al.* (2004) and Soomaroo and Murray (2012) has recommended this method to reduce fire risk. Regular drills should be conducted to acquaint employees with evacuation routes and procedures. This can be done efficiently by working in partnership with local fire departments. Earlier research has also supported this finding (Smith and Trenholme, 2009; Azad *et al.*, 2018).

Formulate an Emergency Action Plan (EAP): The EAP outlines the actions for employees those need to follow during emergencies. An effective EAP guides industries in establishing a reporting mechanism for fires or other crises and in developing clearly demarcated evacuation processes and escape routes, each designated with proper signage. It delineates the precise roles and responsibilities of emergency personnel. An EAP also provides clear instructions on what to do after the evacuation process is complete. Furthermore, the EAP specifies the rescue and medical assistance of workers, if necessary. Finally, an EAP assembles a list of personnel assigned with specific responsibilities, representing whom to contact for further information or clarification of duties. OSHA provides detailed instructions for developing an EAP that industrial establishments should follow (OSHA, 2020c).

Formulate an Emergency Response Plan: Develop and periodically assess a plan that outlines protocols for fire reporting, emergency exit procedures, personnel evacuation, and collaboration with local fire departments.

Infrastructure Planning and Regulatory Measures: The materials utilized in building construction and the products produced within the building significantly influence the spread and intensity of fire. Therefore, industrial infrastructures must be built in accordance with the national building code. Regulatory bodies, such as the DIFE, must ensure that all industrial structures adhere to the Bangladesh National Building Code (BNBC) and fire safety regulations. Penalties should be imposed on unapproved constructions, and regular inspections must be performed to ensure compliance with regulations (BNBC, 2020; DIFE, 2023). Furthermore, fire-resistant materials must be used in construction, whereas combustible and substandard materials should be strictly prohibited. Before granting operational permission, all industrial structures must obtain a fire safety certificate from the FSCD confirming that all structural and operational fire safety measures are in place (FSCD, 2023).

Optimisation Problem: In most cases, it is found that industries have many deficiencies in their safety management systems. Industry owners must prioritise compliance requirements to implement fire prevention, fire safety, and emergency response management systems that protect their businesses, reputations, and ensure sustainability.

Policy Update: Fire safety policies must be routinely reviewed and updated to reflect any changes to the facility or regulations, ensuring ongoing improvement in fire safety practices. By adhering to these recommendations, industrial facilities can significantly enhance their fire safety protocols and establish safer working environments for all personnel.

Ensuring Stiff Punishment of Offenders: To reduce the recurrence of fire hazards in industries, it is essential to ensure strict, consistent punishment for those responsible. As highlighted by Ekramuzzaman (2024), factory owners who have previously violated fire safety regulations face very little consequence or minimal accountability, which, in turn, indirectly encourages other factory owners to neglect compulsory fire protection measures. Implementing strict legal action against offenders not only serves justice but also motivates factory owners to invest in effective fire safety systems, ultimately protecting both workers and assets from the risk of fire disasters.

Conclusion

Industrial fire hazards in Bangladesh are a major concern, posing significant risks to worker safety, industrial assets, environmental integrity, and national economic growth. Despite advancements in export-oriented garment factories, many other industrial sectors continue to face devastating fire risks due to widespread noncompliance with fire safety regulations, inadequate firefighting equipment and safety systems, improper storage and handling of hazardous chemicals and goods, insufficient training and experience among workers, and inadequate fire exits. Hence, effective fire prevention strategies are necessary to mitigate this hazard risk. This study, supported by KII and document reviews, emphasises that effective fire prevention is not simply a technical exercise; it requires a strong safety culture embedded within organisational practices and a shift towards proactive safety management. Fire prevention must be a comprehensive, multifaceted approach that incorporates hazard identification, safe work practices, regular equipment maintenance, employee training, the installation of effective fire protection systems, and the formulation and implementation of both an emergency action plan and an emergency response plan. Establishing and maintaining such a system requires significant effort and commitment from management, as well as support from employees. Fire safety procedures and practices must be regularly reviewed and updated to reflect operational changes, technological advancements, and lessons learned from incidents. Fire prevention is an ongoing process that requires persistent observation, adaptability, and institutional support to ensure a secure working environment for all personnel. As industrial activity increases across the country, safety protocols must adapt accordingly. By adopting a comprehensive fire risk management strategy and strengthening intersectoral collaboration, Bangladesh's industrial sector can evidently reduce the frequency and severity of fire-related incidents. Stricter regulatory enforcement and a shift from reactive to proactive fire safety practices are imperative to safeguard workers, preserve assets, and protect surrounding communities and the environment.

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Author contributions

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