Exploring the Trends & Determinants of Land Use Land Cover Changes in Three Coastal Polders of Bangladesh through Remote Sensing & Qualitative Approaches

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Abstract

Coastal land use practices play a crucial role in ensuring a country's food security. National and international support for expanding shrimp farms has led to extensive land use changes in coastal Bangladesh. People have expressed resistance to shrimp farming due to its negative environmental consequences. Our study aims to explore the determinants of land use practices in Polder 22 and its neighboring Polders 21 and 22 through the lens of the anti-shrimp movement of the 1990s. We have identified various determinants, including motivations related to environmental conservation and vice versa. Our findings reveal significant changes in land use and land cover in the surrounding polders, with Polder 22 largely remaining shrimp-free in most cases.

1. Introduction

1.1. Background of the Study

Coastal land use land cover pattern plays an important role in providing storm buffering, food control, and habitat for fish & other species (Yagoub & Kolan, 2006). Change in LULC is a vital ecological issue. Warming climate followed by global climate change usually occurs in the coastal regions (Bajocco et al., 2012). These changes are driven by various socio-economic, climatic & physical factors. Both anthropogenic & natural disasters may result in a significant impact on countries overall economy & livelihood of its citizens (Huang et al., 2008; Kaliraj et al., 2017). Ecological sustainability may depend on human activities both on local & global scales (Bucx et al., 2014)

19 districts of Bangladesh are situated in the coastal belts which cover around 32% of the total area of the country (Huq & Rabbani, 2014). The coastal region of Bangladesh is blessed with the world's largest forest (Sundarban), minerals, salt & adequate fisheries resources. It is also a potential place for natural gas exploration both in onshore & offshore areas (Michel and Pandya 2010). Coastal people of Bangladesh depend on its natural resources greatly & it carries potential appeal for ports, tourism & other developments (Uddin et al., 2013).

The land use of the coastal region of Bangladesh has been showing a frequently changing trend over the last 60 years. Rice was the main crop in the area in the 1950s (Islam & Ahmed, 1970). Over time, rice production decreased due to salinity intrusion & coastal flooding (Ahmed et al., 1988). World Bank & other funding bodies invested in a coastal embankment project to build an embankment on the coastal area to protect agricultural lands from tidal flooding. Those projects were implemented between 1960 to 1980 in different phases. The main motto of the project was to increase rice production (Islam, 2004). However, it created negative impacts on the coastal ecosystems. Rice production was increased just after the construction of the embankment. But it had dropped down again by the 1990s. Inadequate management & Poor maintenance were the main reasons behind water congestion inland areas, which caused the failure of several embankments. Then rice farmers started aquaculture practices instead of agricultural production.

They used to cultivate shrimp (Black tiger). Paddy fields & some parts of the Sundarban were converted into aquaculture ponds as a result of this land use transformation. Those aquaculture ponds are locally called "Gher". Local vegetation, food productivity fish & plant diversity faced an adverse effect of dramatic salinity intrusion caused by increased shrimp cultivation over the last decades (Islam et al., 2012). Khulna, Satkhira, Bagerhat & Patuakhali were considered the worst salinity-affected areas of the coastal regions of Bangladesh (SRDI, 2010). Various degrees of salinity intrusion were observed among 70% of the land of Khulna & Barishal Divisions (Biswas et al., 2015).

The shrimp expansion in the early 1990s faced resistance from some peasants and landless people throughout South Asia (Ahmed, 1997). In Bangladesh, Polder 22 of Paikgacha Upazilla in Khulna exhibited resistance to shrimp farming, contrasting with the neighboring polders that experienced significant shrimp expansion over the last 30-40 years (Mahtab, 2020; Cons & Paprocki, 2014).

Our study aims to investigate the determinants of land use in Polder 22 and its surrounding areas. Additionally, we will analyze the corresponding land use changes revealed by remote sensing data.

1.2 Objectives of the Study

i) Investigating the factors influencing land use in Polder 22 and its neighboring areas through the lens of the anti-shrimp movement.

ii) Assessing land use and land cover changes in Polder 22 and comparing them with adjacent polders since the incident in the 1990s.

2. Literature Review

2.1 Coastal Land Use Practices & Challenges.

The impact of salinity intrusion on coastal land use is a critical concern in Bangladesh, where approximately 30% of cultivable agricultural land is in the coastal region (Haque, 2006). The vulnerability of this vast coastal area to different degrees of inundation, exacerbated by the specter of increasing salinity due to rapid climate change, poses significant threats to agriculture, forestry, and fisheries. Various studies have shed light on the adverse effects of salinity intrusion, particularly its compulsion on agricultural practitioners to alter land-use patterns. Miah et al. (2020) conducted a review focusing on Jessore, Khulna, Satkhira, and Bagerhat, revealing that unplanned gher expansion is a major contributor to salinity increase, leading to the degradation of agricultural lands and impacting food security. The study recommends salinity adaptation training for farmers and the development of saline-tolerant crop varieties.

Furthermore, investigations into the environmental impacts of shrimp aquaculture by Kabir & Eva (2014) in Chandipur village, Satkhira, found that poor drainage systems and continuous shrimp farming contribute to salinity intrusion. Toxic metals in shrimp pond soil further exacerbate the issue. Habiba et al. (2013) identified sea-level rise, Farakka barrage, shrimp farming expansion, tidal floodings, and excessive groundwater use as major causes of salinity in coastal Bangladesh. They proposed adaptation strategies by highlighting the adverse effects on food security, water safety, agriculture, fisheries, ecosystems, and livelihoods. Hossain & Zaman (2018) focused on adaptation practices among coastal villagers, noting gender-based disparities in adaptation capability and suggesting government intervention to enhance women's capacity.

Additionally, Parvin et al. (2017) analyzed coastal land-use changes, emphasizing the significant increase in shrimp culture land at the expense of agricultural land, influenced by salinity intrusion and forced land ownership transfers. They recommended multi-dimensional monitoring approaches, including GIS-based systems. Kabir et al. (2016) conducted a review on farming adaptation in coastal Bangladesh, comparing the profitability, riskiness, and sustainability of shrimp culture and agriculture. They found that shifting to a different cropping system, including saline-tolerant rice species, proved more economically viable after facing problems such as soil salinity intrusion and adverse impacts of shrimp cultivation.

In the study conducted by Pratheepa et al. (2023), the intricate socio-ecological contradictions of land degradation in coastal agriculture are dissected, focusing on the case of CVP, a coastal village grappling with severe soil salinization. The authors shed light on the confluence of factors, such as geographical location, historical freshwater scarcity, political conflicts over river resources, illicit sand mining, unregulated shrimp farming, and the aftermath of the 2004 tsunami. Their investigation uncovers the significant role of global and national policies promoting shrimp aquaculture as a key driver of soil salinization, resulting in land degradation and altered land use patterns. Furthermore, the differentiated impacts on marginalized groups along the lines of class, caste, and gender emphasize the necessity for a nuanced understanding of the interconnected environmental and social dimensions of land degradation in coastal regions.

Flaherty et al. (1999) contribute valuable insights in their article, "Rice Paddy or Shrimp Pond: Tough Decisions in Rural Thailand," delving into Thailand's pivotal role as a major producer of cultured shrimp. The study traces the development of inland shrimp farming, particularly in Thailand's rice-growing Central Plain, elucidating its impact on the national economy and the global shrimp supply. Despite environmental constraints and disease outbreaks prompting the abandonment of coastal culture areas, Thailand has maintained high shrimp production. The authors highlight the economic and environmental dynamics surrounding the transition from traditional crops to capital-intensive shrimp farming in both upland and lowland areas of Southeast Asia. The article scrutinizes the government's responses, including proposed bans and enforcement challenges, emphasizing the broader impact on rural communities, especially in Asia and Latin America. The controversial shift from rice paddies to shrimp ponds in Thailand's Central Region underscores the multifaceted environmental and social dimensions of this complex natural resource management issue.

Ratnasari (2023) takes a comprehensive approach in evaluating the vulnerability of farmers' livelihoods in coastal areas, employing the Livelihood Vulnerability Index (LVI) and Photovoice methods. The study explores the impacts of shifting slow and fast variables, including climate change, commodity price fluctuations, natural disasters, and land conversion into shrimp ponds.

Coastal farmers, heavily dependent on agriculture, face challenges adapting to changes that significantly disrupt traditional agricultural systems, affecting productivity and economic sustainability. The analysis uncovers exposure to natural and social disturbances, sensitivity in income dependence on agriculture, and vulnerabilities in adaptive capacity, encompassing physical, economic, human, and social capital. Integrating quantitative and qualitative methods provides a holistic understanding of the challenges faced by coastal farmers, emphasizing the need for collaborative strategies, policy changes, and improved management practices to address vulnerability in the face of shifting environmental and economic variables.

2.2. Anti-Shrimp Movement Worldwide

Ahmed (1997) compiled resistance movements against shrimp farming across South Asia, highlighting environmental degradation, social injustice, and the disruption of traditional livelihoods. In Andhra Pradesh, the aftermath of a 1996 cyclone submerged Kurru village, reflecting the impact of the Blue Revolution. Transitioning from rice to shrimp farming turned Nellore into an industrial belt, sparking coastal protests and a momentum of resistance, including Black Day in December 1994 and the Gram Swaraj Movement advocating for land and self-reliance. Tamil Nadu's LAFTI (Land for the Tillers' Freedom Initiative) fought against the conversion of the 'rice bowl,' while Orissa's Save Chilika Movement utilized civil disobedience tactics. In Khulna, Bangladesh, an invasion in 1990 triggered resistance, marked by the death of Karunamoi, symbolizing bravery. Shrimp farming's acknowledged environmental and social impacts led to the formation of Shrimp-Free Zones and movements against violence and land grabbing. In Cox's Bazaar, the Badarkhali community, post-cyclone, faced deforestation and unemployment due to shrimp farming, prompting the Nayakrishi Andolan—a movement focused on sustainable agriculture and self-reliance.

Mahtab (2020) extensively documented the Mass Mobilisation during the 1990 Anti-Shrimp Movement in Polder 22. The movement gained momentum after the tragic death of Karunamoyee Sarder in November 1990, who was leading a protest against shrimp aquaculture in Paikgacha, Khulna, Bangladesh. Karunamoyee and fellow landless protestors faced a violent attack, orchestrated by hired goons of a local shrimp farm owner. This incident transformed the ongoing mobilization of Polder 22 peasants into a widespread movement against shrimp aquaculture.

Notably, Polder 22 has since remained free of shrimp cultivation, and an annual gathering of thousands commemorates Karunamoyee as a martyr. Drawing from oral and textual sources, this microhistory delves into the intricate dimensions of peasant agency, solidarity, aspirations, and motivations that initiated their resistance. It also explores how alliances with political parties and civil society organizations, specific to the 1990s Bangladesh context, elevated the local resistance into a mass movement. The study investigates how Karunamoyee and the movement have evolved into symbols representing peasant rights and struggles, transcending the immediate context of Polder 22 for the people involved.

2.3 Land Use Land Cover Change Detection Using Remote Sensing Techniques

Land Use Land Cover Change (LULCC) detection through remote sensing applications has become a pivotal aspect of Earth System Science, enabling a nuanced understanding of human-environment interaction. Over the last decades, advancements in Earth observation sensors with heightened spectral and spatial resolutions have revolutionized the cost-effective classification of land cover types. This review encompasses recent works on LULC, both globally and locally, shedding light on the transformative dynamics observed in various regions. Barai et al. (2019) conducted a comprehensive study on the expansion of shrimp cultivation in Bangladesh, utilizing Landsat imagery to track changes over 30 years and revealing significant agricultural to aquacultural land transformations. Karim & Zhang (2019) focused on shrimp farming decline in Rampal, Bangladesh, mapping LULC changes over 18 years and highlighting the need to declare shrimp cultivation areas as protected zones. Rahman et al. (2017) employed CA-ANN models for predictive land-use change analysis in Assasuni, Bangladesh, emphasizing sustainable land-use management. Abdullah et al. (2017) explored the heterogeneous LULC pattern of coastal Bangladesh, utilizing Random Forest classifiers to reveal vegetation cover losses and increased agricultural lands.

Hu et al. (2019) concentrated on LULCC in Guangxi, China, identifying vegetation loss from 1990 to 2017 and utilizing the Markov chain model for detailed visualization of land use patterns. Buchner et al. (2020) studied topographic image correction and land cover change in the Caucasus Mountains area, emphasizing the importance of accurate classifications for monitoring mountainous ecosystems. Camilleri et al. (2016) tackled the classification of manmade and natural coastal wetlands in Spain, adopting case-specific methods and integrating aerial photographs, Landsat data, and local interviews. Matlhodi et al. (2019) defined LULC changes in the Gaborone dam catchment in Botswana, observing dramatic vegetation losses over the observed period. Shawul & Chakma (2019) focused on the upper Awash basin in Ethiopia, using the Land Change Modeler to predict future LULC changes, revealing significant urban and cropland increments alongside vegetation losses. This synthesis underscores the diverse applications of remote sensing technologies in unraveling the complexities of LULCC across different regions and ecosystems.

3. Study Area & Methodology

3.1 Study Area

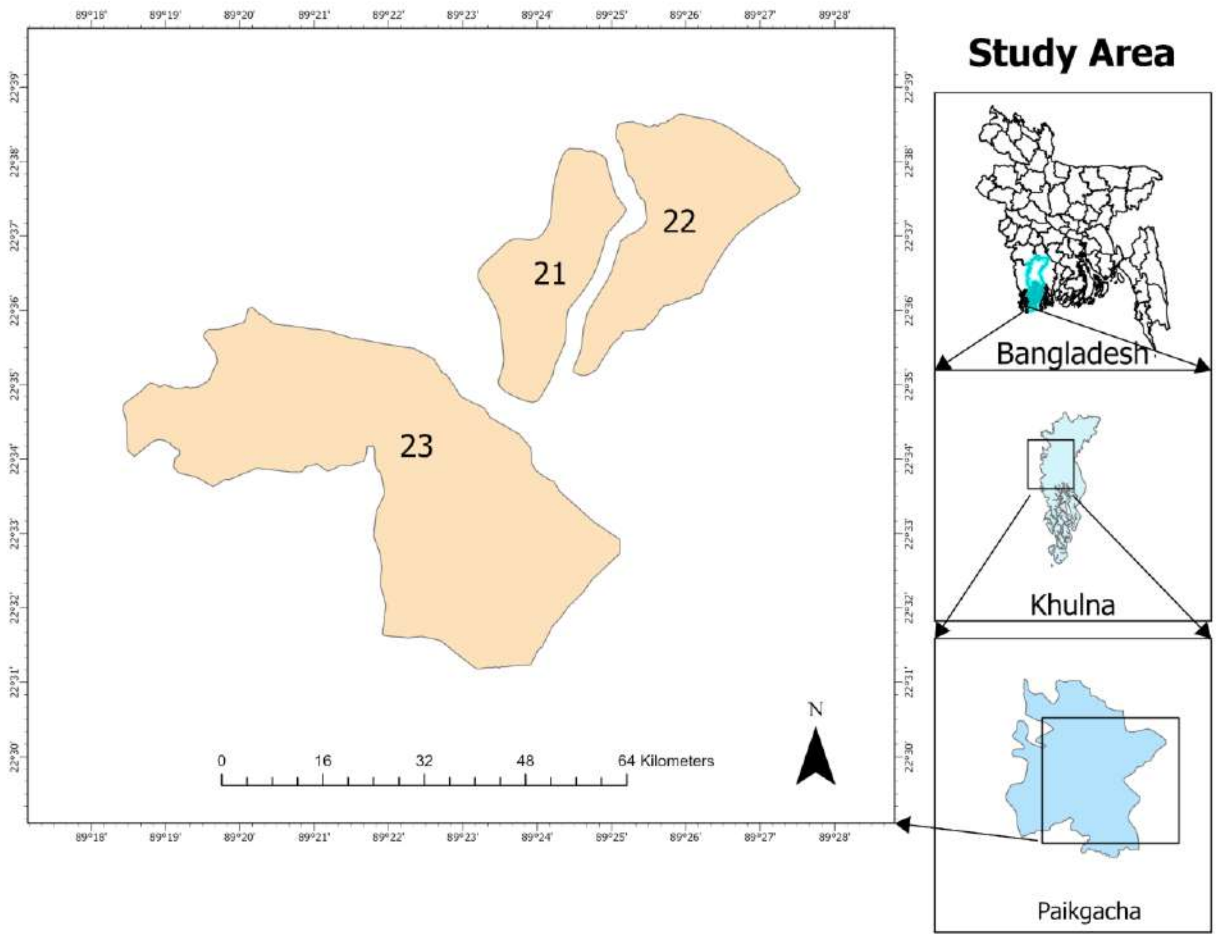

Figure 1. Study Area.

Our study area is located on Paikgacha Upazilla of Khulna Zila in Bangladesh. Selected polders are surrounded by Shibsa, Kobadak, Deluti & Vadra rivers. Crop Calendars are provided for the better understanding of the polders.

3.2.1 Crop Calendar of Polder 21

The yearly activities of the farmers of Polder 21 started with preparing the Gher in February. The land is prepared by applying various chemicals and fertilizers. In early March, the dyke of the

Ghers is repaired and fish larvae are released after filling the gher with river water. The fish are sold before the fresh water comes to the river in July. Then, the land is prepared for rice cultivation by raising freshwater and applying lime and fertilizer. After preparing the seedbed at the end of July, planting occurred in early August. rice is harvested in the middle of December. This schedule of cultivation has been going on for almost 40 years.

3.2.2 Crop Calendar of Polder 22

According to the Gregorian calendar, farmers begin their annual activities by preparing the watermelon field in February. Watermelon is harvested at the end of April. Alongside watermelon cultivation during this time, sunflower, pumpkin, and other vegetable crops are also grown. When the flow of freshwater begins in the river around July, farmers start lifting freshwater for rice cultivation. The seedbed preparation and rice plantation take place in August. Rice is harvested at the end of December.

In the past, in some areas of Polder 22, shrimp were cultivated alongside rice similar to Polder 21. During January, brackish water was lifted, and after changing the brackish water with fresh water, rice was transplanted around July-August.

3.2.3 Crop Calendar of Polder 23

Most of the lands in Polder 23 are used for shrimp cultivation. Brackish water from the river is the primary source for shrimp farming. By the end of January, the used brackish water is released from the pond, and the dykes are repaired. Then the farmers prepare the land for next season using fertilizers and other chemicals. They refilled the Gher with brackish water from the river, and new shrimp larvae were released. The water in these Ghers is periodically exchanged.

On the other hand, in some small portions of this polder, where rice cultivation is practiced during the period of freshwater in the river, similar to Polders 21 and 22, seedbeds are prepared in August for rice cultivation. Planting begins, and rice is harvested in mid-December.

3.3. Satellite Data Acquisition & Analysis

All the Satellite Images were downloaded from USGS Earth Explorer. We used Landsat level 2 collection 2 data. Necessary corrections were performed by its provider. Supervised classification was conducted through the Maximum likelihood classifier technique (Hord RM, 1982). This is one of the most accurate & widely used techniques for image classification that follows per-pixel methods & takes spectral information of land cover classes into account (Qian et al., 2007).

Table 1. Details about the Satellite Images Used for the Study

SN	Date of Acquisition	Sensor	Satellite	Spatial Resolution
1	16.03.1989	TM	Landsat 4-5	30
2	27.11.1989	TM	Landsat 4-5	30
3	27.02.2006	TM	Landsat 4-5	30
4	12.12.2006	TM	Landsat 4-5	30
5	07/04/2023	OLI	Landsat 8-9	30
6	25/11/2023	OLI	Landsat 8-9	30

The field study was conducted on 26-28 November 2023. An Android smartphone with a GPS feature was used for collection site training points for the image of 25/11/2023.m

For the rest of the images; No historical images or datasets were available for the site training. There is enough research available in the sector where Google Earth Images are used for site training & validation (Hasan et al., 2023). However, in that case, it was not possible to do so as Google Earth images are composites of multiple images & our study area has heterogeneous land use characteristics. Historical site training datasets were developed based on the developed crop calendar. We gathered historical land use practice information considering the heterogeneity of the land use practices from the in-depth interview data.

ArcGIS 10.5 was used for the overall image processing; from band composition to calculating area statistics. The rest of the calculations were conducted by MS Excel. All the activities for image classification are summarised below on the flowchart.

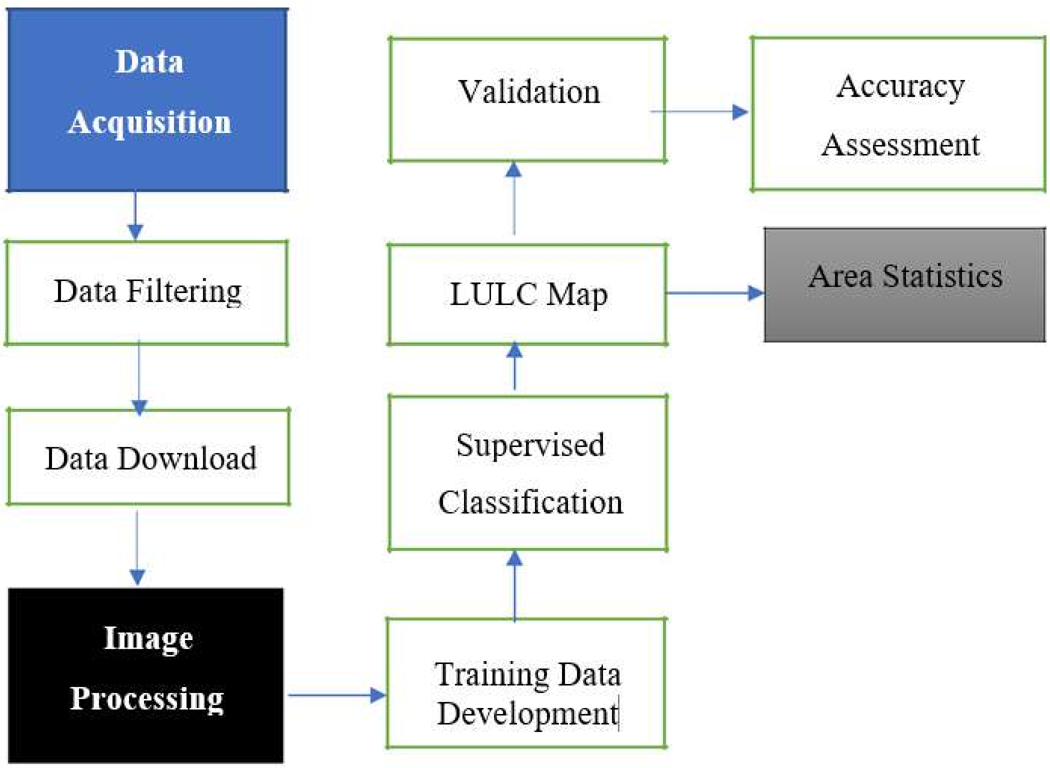

Figure 2. Summarized workflow for Data Acquisition & Analysis

3.4 Qualitative Data Collection & Analysis

A semi-structured questionnaire was created for conducting interviews. The recorded interviews were transcribed, and thematic coding was carried out using the methods outlined by Braun and Clarke (2006). Those steps are:

1. Familiarization with the Data
2. Generating Initial Codes
3. Searching for Themes
4. Reviewing Themes
5. Defining and Naming Themes

6. Writing the Report

Recorded Audio, Transcribed documents & qualitative codes are stored in Google Drive.

4. Results & Discussions

We have attempted to observe the pattern of land use change through interviews with our respondents and analysis of remote sensing data. Every type of land use determinant has a different background & story. In this chapter, we will present our findings from both qualitative and quantitative data.

4.1 Actors in Land Use Dynamics

In our study area, we identified five actors involved in land use dynamics:

a) **Landless peasants**: Individuals without land who either work on government-owned or others' land as laborers or cultivate the land by leasing it.
b) **Small-scale farmers**: Individuals with small landholdings (5-10 bighas).
c) **Large-scale farmers**: Those who possess more than 10 bighas of land & cultivate it by themselves as well as the landless peasants & small-scale farmers.
d) **External Shrimp Farms**: Businessmen engaged in shrimp farming who lease land from local landowners for large-scale shrimp farms.
e) **NGOs**: Non-profit organizations that mobilize peasants to protest against shrimp farming.

4.2. Characteristics & Determinants of Various Land Use Changes

Our study area is surrounded by the Shibsha, Kobadak, Deluti, and Vadra rivers. The flow of brackish water begins in the rivers in January and fresh water is available in July. People depend solely on river & rainwater harvesting for all kinds of agricultural or farming activities. In the last 35 years, five types of major land use transitions have occurred. Here, we will elaborate on the major types of land use changes and their associated determinants.

	Major Land Use Change Types				
	Past		Present		
	Freshwater Season	**Brackish Water Season**	**Freshwater Season**	**Brackish Water Season**	**Polder**
A	Rice and Vegetables	Fallow Land	Rice and vegetables	Watermelon and other Crops	22
B	Rice	Shrimp Gher	Rice	Fallow Land	22
C	Rice and Vegetables	Fallow Land	Rice	Shrimp Gher	21, 23
D	Rice and Vegetables	Shrimp Gher	Shrimp Gher	Shrimp Gher	23, 21

Table 2: Major Types of Land Use Changes

4.2.1a. Type A (Increased Agricultural Activities)

***"We only grow rice once a year here. We plant watermelon seeds in February and watermelon is sold in April."* - A farmer of Polder 22**

This type of land transition is specifically observed in Polder 22. This part of Polder 22 is located slightly inland from the river. Rice along with winter vegetables is grown here in the rainy season, and other crops such as watermelon, corn, etc. are grown in the dry season by stored fresh water. In the past, vegetables were grown after rice while there was a flow of fresh water in the river, and the land would remain fallow when brackish water came in.

4.2.1b. Determinants of Land Use Change: Type A

i) Economic Factors

***"Rice farmers are making good money. Millions of taka are coming into our polders from watermelon as well."* - A farmer of Polder 22**

In the past four or five years, watermelon has emerged as one of the most profitable crops for this type of land. The yield from watermelon cultivation in one bigha of land can be sold for 80-90 thousand taka.

***"Those who have 50-100 bighas of land here were interested in doing shrimp gher. And those who are landless or have only a few bighas of land never wanted gher farming here. Because if the land is used for shrimp farming, the amount of work will decrease."* - A Farmer of Polder 22**

One of the main reasons why this type of land did not transition to brackish shrimp farming was the fear that the amount of work would decrease. The majority of supporters of the movement against brackish water gher in Polder 22 were landless farmers, who cultivated other people's land or worked as day laborers. Their resistance stemmed from the concern that if the control of land goes into the hands of big gher owners, there will be a livelihood crisis, and the environment will be disrupted.

***"If someone does shrimp farming, the risk of loss increases. Agriculture is my only source of income. So I didn't want to take the risk of making a gher."* - A Farmer of Polder 22**

Moreover, local farmers perceive shrimp farming as a risky business. The fear of economic loss was also one of the primary reasons why they refrained from establishing a gher.

ii) Environmental Factors

"Shrimp farming is harmful to the environment, and it is not possible to grow rice properly on that land. so we have never done shrimp farming."

The farmers here believe that shrimp farming is harmful to the environment. According to them, this is one of the main reasons why they refrain from shrimp farming.

iii) External Influence & Social Pressure

Some respondents supporting brackish water shrimp farming perceived NGO involvement in the anti-shrimp movement as an 'External Influence.' Meanwhile, respondents from various groups considered the influence of Gher Businessmen in the locality as another 'External Influence.' We've categorized and will discuss both NGO and Gher Businessman's involvement under the same category.

"People here don't like brackish water ghers." **- A farmer of Polder 22**

In this part of Polder 22, people socially dislike brackish water ghers. In the 1990 anti-brackish water movement, local landless farmers started a movement that later spread to different areas. The then influential gher businessman and politician Waheed Ali Biswas wanted to make a gher in this polders. On the other hand, an NGO called "Nijera Kori" mobilized landless farmers in that movement against brackish water ghers.

"He had signed a contract with several landowners that he would make a gher in Polder 22. He had tried to bring in brackish water with a group of people. On the other hand, there was an organization called "Nijera Kori" there, they said they would not let the gher be made. In that conflict, two local people who were against brackish water were killed." - A farmer of polder 22 describing the conflicts between Mr. Wazed Ali & local people

As a result of that movement, people refrained from making ghers due to legal & social bindings.

Shrim

iv) Resource-associated factors:

Here, people store freshwater from the river and use it during the dry season for cultivating watermelon and other crops. We observed this practice only in Polder 22. Since people do not cultivate shrimp in the dry season, there is no possibility of mixing freshwater storage with brackish water.

Figure 3: Freshwater storage beside the agricultural field

4.2.2a. Type B (Decreased Aquculture)

"The atmospheric moisture in this region carries saltwater, and there are occasional leaks in the polder embankment. As a result, only rice cultivation is feasible during the freshwater season." - A farmer describing land use change type B

This type of land use transition is observed in the southern part of Polder 22. This section is the narrow part of the polder, surrounded by the river on three sides, and its proximity to the river is remarkable. Brackish water was introduced to this part in 1988 but not to a massive extent. 30-35 years ago, people used to cultivate rice during the freshwater season and shrimp in some of the lands during dry seasons. The Rest of the lands kept fallow during brackish water seasons. Around 15-20 years ago, people started doing seasonal shrimp farming in most of the lands of these land types. Currently, people only cultivate rice and vegetables during the freshwater season, and the rest of the time, this land is kept fallow due to various reasons. Those reasons will be discussed in the next section.

4.2.2b. Determinants of Land Use Change: Type B

i) Economic Factors

"Due to virus & other diseases outbreak in shrimp farming, we are cautiously stepping back from shrimp farming." - A former Shrimp farm practitioner.

Despite the ongoing opposition to brackish water, a few landowners initially showed interest in shrimp farming. They began establishing brackish water ghers in these polders around 1988. However, they eventually discontinued gher farming due to the outbreak of viruses in shrimps, which caused financial losses. Since then their land kept fallow during dry seasons.

ii) Environmental Factors

"In addition, seeing the environmental disaster, we lost interest in shrimp farming." - A former shrimp farmer of Polder 22 expressed their concern for the environment.

Even those who supported shrimp farming in Polder 22, after a while, also came back from shrimp farming considering the environmental aspects.

"After initiating shrimp farming, a water crisis emerged. Within a few years, the once-green environment began to gradually vanish." - A shrimp farmer describing the consequences of brackish water intrusion

It seems that environmental degradation serves as a determinant, influencing their decision to avoid shrimp farming based on their lived experiences.

iii) External Influence

"If we could have built a gher at that time, we would have had a house in Dhaka or Khulna." - A former shrimp farmer expressing his regrets for not being able to do shrimp farming in the 1990s decades.

This part of Polder 22 is located near the river, so the land would remain fallow in the dry season due to the influence of salinity. The landowners of this land tried to make ghers around 1990, but they could not make ghers on a large scale. They started making ghers again 15-20 years ago. But they came back from ghers considering viruses and environmental aspects.

However, many people regret not being able to make ghers around 1990. They believe that gher farming was profitable at that time. They think that they have fallen behind economically due to the obstacles of the anti-shrimp movement influenced by NGOs.

4.2.3a. Type C & D (Rice / Fallow to Shrimp Gher)

"In 1989, brackish water ghers were first initiated in our Polder 21. Before that, rice was cultivated for six months, and the land remained fallow for the rest of the year." **-** A farmer describing the land use change type C.

This type of transition is observed in most parts of Polder 21 and the riverside area of Polder 23. Around 35-40 years ago in Polder 21, people cultivated rice with winter vegetables, and the land was left fallow during the dry seasons. Now, the entire area is interchangeably used for rice and shrimp cultivation, except for 250 acres of land, which is dedicated to shrimp cultivation throughout the year.

On the other hand, Polder 23 is comparatively larger. Only those who have access to fresh water from the river can cultivate rice; otherwise, people have no other options rather engaging in shrimp farming throughout the year.

Figure 4. Shrimp Farms & Sluice Gates

"The practice of shrimp farming throughout the year was started by outsiders, the big gher owners. Even now, the small landowners around the big ghers cannot cultivate rice even if they want to due to brackish water." **-** A farmer of polder 22 describing the land use change type D

Shrimp farming throughout the year started in the early 1990s. Large landowners leased their land to outsider shrimp businessmen, and they pursued shrimp farming as they pleased. Small-scale farmers and peasants didn't find any option but to engage in shrimp culture on their land throughout the year, abandoning rice cultivation.

4.2.3b. Type C & D (Massive Expansion of Aquaculture)

i) Economic Factors

Poverty and Early Struggles:

"In our childhood, we were in great poverty. We ate seeds of water lily fruits to satisfy our hunger. Even if there were no Gher, the poverty was very high." - A farmer of Polder 23 expressing their motivations to start shrimp farming.

The economic condition was not very good before starting the brackish water gher in the Polders 21 & 23. At that time, only rice was grown during the freshwater season, and the land was left fallow when brackish water came into the river. According to some people, they ate the seeds of water lilies in the urge of hunger.

"In a gher, a poor woman will earn 300 taka from 8 am to 1 pm" - a shrimp farmer is describing the opportunities of a shrimp farm

Currently, those who work in the gher will get 300 takas if they work from 8 am to 1 pm (polder 23), and 600 takas if they work until 4 pm (polder 21).

Increased Population

"When I was a child, one bigha of land would yield seven to eight mann (40kg) of rice, which was sufficient for the population at that time." - A farmer of Polder 23

People cultivated rice during the freshwater season, and the land would lie fallow the rest of the time. They stored rice for their yearly consumption and sold the surplus. As the number of family members increased, the production level did not rise proportionally. Consequently, people opted to start shrimp farming.

With the cultivation of various salt-tolerant varieties of rice, the production level increased. The income earned from the ghers became an additional source of revenue. However, as the population continued to rise, people were motivated to establish shrimp ghers in the hope of generating more profits, rather than keeping the land fallow for six months.

Failed Aspirations

"After starting shrimp farming, some external owners invested one taka and made a profit of ten taka within a few days. We tried to follow their steps and ended up facing significant economic losses." **-** A farmer describing how shrimp gher initiated in polder 23

In the early 1990s, leasing land to large gher farms was considered a profitable and fascinating livelihood. Hari is a local system where people rent their private land for a specific amount of money and time. The advance of hāri money could be used to invest in other businesses or to improve one's standard of living.

In the early days of shrimp farming, Outsiders who owned large ghers in different areas started shrimp farming in Polder 21 & 23 by paying local landowners 1,500 takas per bigha per year. The hāri price ranged from 1,500 takas to 3,000 takas were given for the next five to seven years. Then, the hāri price remained at 3,000 taka to 5,000 taka for another eight to ten years. Then, it gradually increased by 1,000 takas per year and has not exceeded 10,000-12,000 taka till now.

"At first, brackish water ghers started here through outside owners. After the outbreak of the virus, outside owners stopped gher cultivation. Then we started shrimp cultivation by contacting them." **-** A shrimp farmer of Polder 23

However, there is also a contrasting perspective. According to numerous individuals, they led prosperous lives by cultivating rice, vegetables, and livestock in addition to rice cultivation. Shrimp farming, on the other hand, put them into severe debt following a virus outbreak, and till now they cannot break the cycle of debt.

ii) Environmental Factors

"My father attempted to cultivate rice during the dry season, but the crop failed to thrive in the salty atmosphere. On the other hand, the produced watermelons being notably small in size.

Consequently, we have since focused on shrimp farming alongside rice cultivation." - A farmer from Polder 21

Previously, most of the land in Polder 21 was used for rice cultivation and the land was left fallow during the dry season. Due to atmospheric conditions and the salinity of groundwater, they were not successful in producing any other crops. Gher cultivation was adopted as a coping strategy.

iii) External Influence

"At first, the shrimp businessman came from outside. They talked to the landowners and motivated them about the opportunities. Then shrimp cultivation started here" - A farmer of Polder 23

Outsiders influenced the large land owners to cultivate shrimp in both Polder 23 & Polder 21.

iv) Resource-Associated Factors

"Here some outsiders own big ghers. They don't let the brackish water down from the big ghers, and they don't let the fresh water in. Because of them, the owners of the small ghers around them cannot even plant rice. Moreover, They control the sluice gates." **-** A farmer of Polder 23

Many of our respondents of Polder 23 mentioned that the water management system is very poor here. The canals are blocked by the siltation process & the sluice gates are controlled by the large gher owners. That's why people don't have any other choices other than cultivating shrimp.

v) Power Dynamics

"In 1984/1985, shrimp cultivation started in this area for the first time. Outsiders had a lot of land here, and when they started shrimp cultivation, there was nothing left for others to do. Everyone was forced to start shrimp cultivation" - A farmer of Polder 21

People who have more lands, If they started doing shrimp farming, the surrounding land cultivators don't have any options to do rice cultivation.

4.3. Land Use Change Detection Using Remote Sensing Techniques

In the previous section, we discussed major land use change types and determinants based on our qualitative data. In this section, we aim to evaluate these findings using our remote sensing data. We have analyzed a total of six Landsat images, encompassing the years 1989, 2006, and 2023, with two images captured during both brackish water and freshwater seasons in each year.

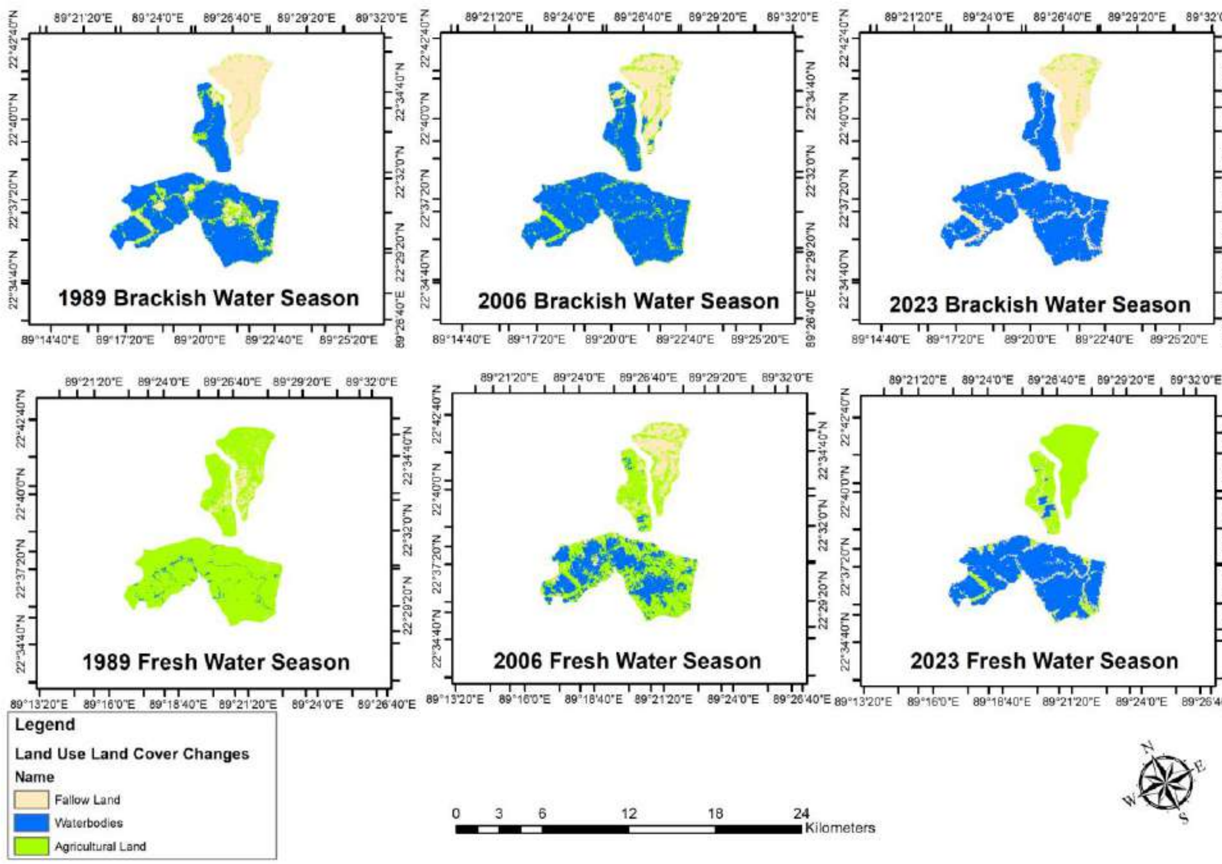

Figure 5. Land Use Changes in our Study Area considering seasonal variations.

Accuracy assessment for the six LULC classifications was done and the Kappa coefficient with were calculated & shown in table .

Table 3. Accuracy Assessment of the Classified Map

Year	Season	Overall Accuracy (in %)	Kappa Coefficient
1989	Brackish	73.33	0.6
1989	Fresh	83.33	0.75
2006	Brackish	76.67	0.65
2006	Fresh	70	0.55
2023	Brackish	86.67	0.84
2023	Fresh	90	0.85

All types of land use changes in different seasons are provided here in tabular format.

Table 4. Land Use changes in different polders during brackish water season.

Year	Polder	Agricultural Land (Sq Km)	Waterbodies (Sq Km)	Fallow Land (Sq Km)
1989	21	1.52	7.92	0.59
2006	21	1.35	8.17	0.51
2023	21	0.01	8.61	1.42
1989	22	0.78	0.01	13.84
2006	22	2.93	0.55	11.15
2023	22	1.25	0.01	13.38
1989	23	6.61	35.18	3.15
2006	23	4.78	39.98	0.17
2023	23	0.05	38.1	6.78

Table 5. Land Use changes in different polders during freshwater seasons.

Year	Polder	Agricultural Land (Sq Km)	Waterbodies (Sq Km)	Fallow Land (Sq Km)
1989	21	8.71	0.04	1.29
2006	21	7.57	0.58	1.89
2023	21	7.08	1.03	1.93
1989	22	11.73	0	2.9
2006	22	5.66	0	8.98
2023	22	14.16	0.01	0.46

1989	23	43.3	1.36	0.27
2006	23	23.19	19.51	2.22
2023	23	2.52	36.62	5.78

4.3.1. Type A (Increased Agriculture) LULC Changes

We observed an increase of 0.47 sq. km in agricultural lands specifically in Polder 22 between 1989 and 2023. This transition was not observed in any other polders.

4.3.2. Type B (Decreased Aquaculture) LULC Changes

We observed a trend of shrimp culture in Polder 22 during the brackish water season in 2006, which subsequently transformed into fallow land by 2023. Additionally, we noted an increase in waterbodies within Polder 22, measuring 0.01 sq. km, in 2006, which then decreased to 0.01 sq. km again by 2023.

4.3.3 Type C & D (Massive Expansion of Aquaculture)

This is the most dominant type of land use change in our study area. Except for polder 22, both polder 21 & polder 23 faced this land use transition more or less.

In freshwater season, Around 1 sq. km of land transformed into shrimp gher in polder 21.

On the other hand, polder 23 encountered a devastating transformation. 40.78 sq. km of agricultural land decreased while 35.26 sq. km of Shrimp gher increased in this polder.

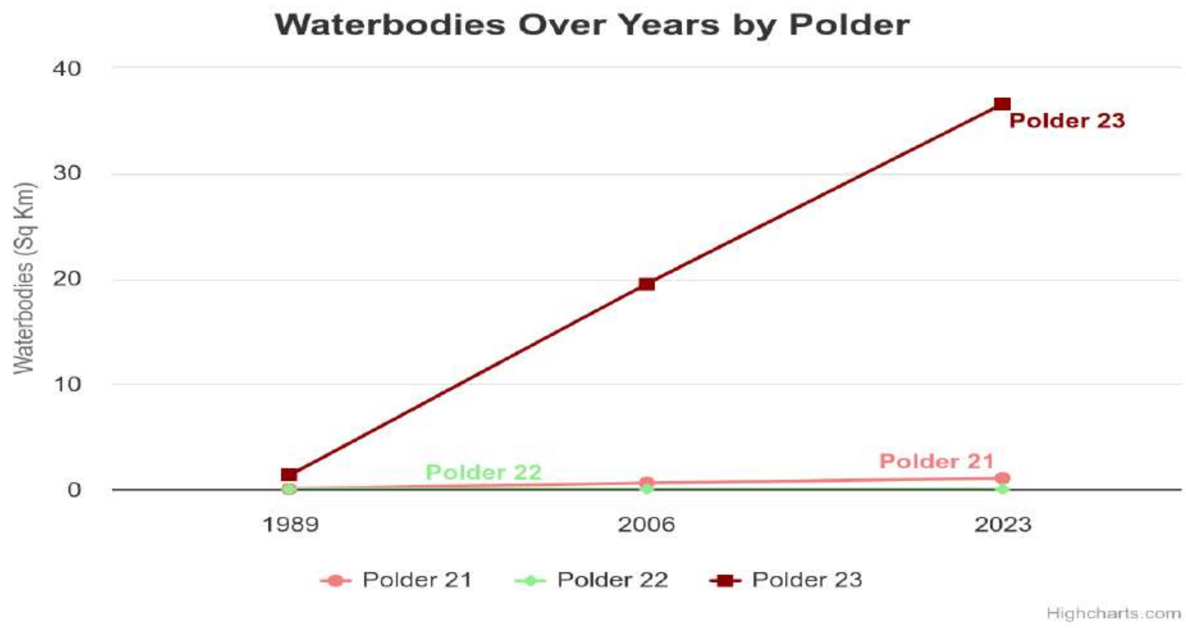

Figure 6. Expansion of Shrimp gher in the polder 23 over the last 35 years.

5. Conclusion

Polder 22 remained shrimp-free because of local resistance & shrimp farmers realized environmental concerns, while people in Polders 21 and 23 faced difficulties. The key reason behind this difference is the control the farmers have over their land and water.

External influences, like big shrimp farm owners played a part in pushing for shrimp farming. The lack of local control in these areas made them more vulnerable to outside influences, leading to a shift to year-round shrimp farming.

This clear difference highlights the importance of policies that empower local communities to decide what's best for their land. Understanding the unique situations in each area is crucial for promoting sustainable practices and preserving the special features of each polder.

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