

# Utilization of Unmanned Aerial Vehicles (UAVs) for Coastal Monitoring in Bangladesh: A Review on Prospects, Challenges and Way Forward

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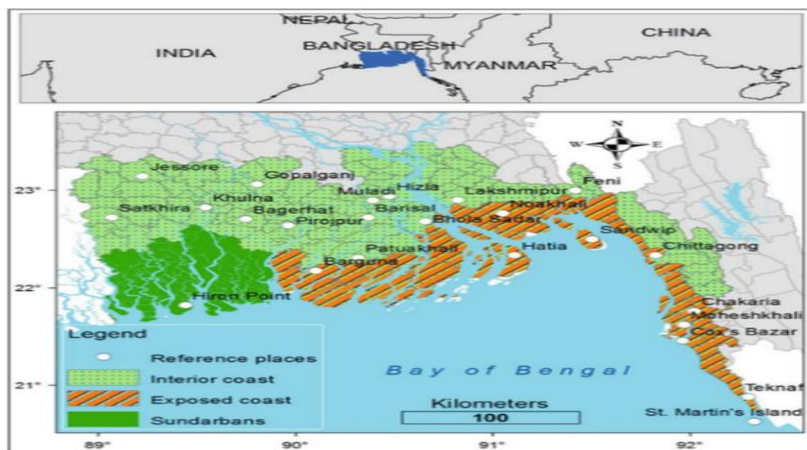
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**Abstract:** Bangladesh is recurrently cited as one of the most vulnerable countries to climate change. Many of the anticipated adverse impacts of climate change, such as sea level rise, higher temperatures, enhanced monsoon precipitation, increase in cyclone intensity etc aggravate the existing stresses that already hindered socioeconomic development of the country. Bangladesh's impressive economic growth was backed by its decades of systematic investments in climate resilience and disasters preparedness. Sea level rise affects the vast coastal areas and flood plain zone of Bangladesh and gradually the situation would be worsened if appropriate measures are not taken timely. Both livelihood options of coastal communities and the natural environment of the coastal zone of the country will be affected adversely by the anticipated sea level rise (50 cm by 2050). On the other hand, the utilization of Unmanned Aerial Vehicles has rapidly evolved over the past decade in different parts of the world involving a variety of fields ranging from agriculture, commercial, coastal monitoring and becoming increasingly used in disaster management or humanitarian aid. Hence, this article aims to explore the prospects of utilization of Unmanned Aerial Vehicles for coastal monitoring in Bangladesh. This study has been initiated by collecting and reviewing primary and secondary data. Mixed-method research methodology has been used which includes both quantitative and qualitative approaches. This study has been conducted under the statistics of inferential analysis consisting t-test, Pearson correlation analysis and regression analysis. It has also considered one-way ANOVA test to examine the significant relationship among the independent and dependent variables. It is evident that applications of Unmanned Aerial Vehicles need to be further explored examining the existing challenges; to focus further on drone assistance for coastal monitoring. It is envisaged that with the sufficient supportive actions and policy measures, the application of Unmanned Aerial Vehicles for coastal monitoring including disaster management in Bangladesh appears to be promising and will improve its effectiveness.

**Keywords:** Climate Change, Sea Level Rise, Coastal Monitoring, Unmanned Aerial Vehicles (UAVs).

## I. Introduction

Bangladesh is frequently cited as one of the most vulnerable countries to climate change because of its geographic location; flat and low-lying topography; reliance of many livelihoods on climate sensitive sectors; and inefficient institutional aspects. The total land area of the country is 147, 570 sq km and consists mostly of low, flat land; 80 per cent of the land is floodplain, and only in the extreme northwest do elevations exceed 30 metres above mean sea level, making the majority of Bangladesh (with the exception of the highlands) prone to flooding. The coastal area of Bangladesh (Map 1) and the Bay of Bengal are located at the tip of the northern Indian Ocean, which is frequently hit by severe cyclonic storms, generating long tidal waves that are aggravated by the shallow bay.



Map 1: Coastal Zone of Bangladesh

Source: warpo.portal.gov.bd

Coastal areas in Bangladesh are on the 'front line' of climate change, directly affected by storm surges, drainage congestion and sea level rise. The World Bank Group's Climate Risk Country Profile exposes Bangladesh's high risk of climate change. The country faces significant economic consequences, with tropical cyclones taxing about \$1 billion of the country's financial budget annually. Coastal challenges, for example, sea level rise and salinity intrusion, are becoming the main problem for millions of people living in coastal areas by the day, affecting agriculture, infrastructure, and biodiversity. By 2050, climate events could reduce agricultural GDP by a third, impacting almost half of the workforce. An estimated 13.3 million people could become internally displaced refugees within the next 30 years. Severe floods could decrease GDP by up to 9%, and environmental degradation and natural disasters are expected to worsen, steering Bangladesh and her population towards an unpredictable future (Report of World Bank Group, 2022).

In Bangladesh, about 46% of its total population live within 10 m above sea level and approximately 50 million people live 5 m above the mean sea level. With sea levels expected to rise by an average of two to three mm per year during the first part of this century, the effects on the coastal areas will be severe including erosion, coastal land subsistence, siltation of river estuaries, reduced sedimentation, waterlogging, and saltwater intrusion. Although Bangladesh now has good early warning systems and cyclone shelters have been constructed along much of the coast, infrastructure and livelihoods are still threatened and severely affected, hampering further development of the coastal areas. If sea levels rise up to one metre this century, Bangladesh could lose up to 15 per cent of its landmass and up to 30 million Bangladeshis could become climate refugees. In their research Mehvar et al (2018) quantified the total loss of about US\$ 0–1 million to US\$ 16.5–20 million to different ecosystem services due to the different levels of relative sea level rise (RSLR) under different Representative Concentration Pathways (RCPs) until 21st century in the west coast of Bangladesh. Islam et al. (2018) have also found in their study that a considerable amount of areas in the south-western part of Bangladesh have been suffering from waterlogging condition. Bangladesh government introduced policies and action plans namely Coastal Zone Policy (CZP) in 2005, Bangladesh Climate Change Strategy and Action plan in 2009 and formulated National Adaptation Program of Action (NAPA) in 2005 at national level to address the SLR induced impacts. Bangladesh is also a leading example for the implementation of community-based adaptation (CBA) measures among least developed countries. Development of adaptation policies for different sectors will help Bangladesh to deal with the crucial hazards of sea level rise. Lobby in the international communities would be helpful to mitigate CO<sub>2</sub> emissions, which is responsible for global warming and sea level rise. Proper mitigation plan and formulating adaptation policies are emerging need to minimize the impacts of sea level rise upon the country. To implement the mitigation and adaptation plan, adequate data, information and coastal mapping are very crucial. Hence, in recent years many countries are successfully using Unmanned Aerial Vehicles (UAVs) for coastal monitoring, mapping and disaster management, such as USA, UK, Australia, New Zealand etc. Whether mapping natural resources or coastal environment through 3D models, simple off-the-shelf drone technology has proven to be an affordable and accessible option for these and similar tasks. So, there is an ample opportunity for concerned authorities to effectively monitor and assess the coastal resources of Bangladesh by adopting simple and easy-to-use methodologies for the utilization of UAVs/drones to support their decision-making processes. Hence, the objective of this paper is to review and explore the potentiality of the uses of UAVs for monitoring coastal environments, bio-diversity and habitats.

## **II. Methodology**

This study has been initiated by collecting required data and information from several research-based databases, peer-reviewed journals, newspapers, e-magazines, and relevant organization's websites to delineate the scenario. Relevant literature on impacts of sea level rise and utilization of UAVs for coastal monitoring and disaster management have been also reviewed. The study was conducted along selected coastal zones of Bangladesh, including Cox's Bazar and Kutubdia, and parts of the Sundarbans. These regions were chosen due to their exposure to coastal erosion, tidal surges and sea level rise. This study adopted a mixed-methods research design, integrating quantitative & qualitative data from field observations and stakeholders' interviews. The overall approach was descriptive and exploratory, aiming to review and explore the potential use of UAVs for coastal monitoring. Structured interviews were carried out with local residents (fishermen, farmers, and women's groups), coastal zone management officials, NGOs and coastal community leaders and environmental researchers. These provided contextual information on coastal changes, community vulnerabilities, and perceptions of UAV-based coastal monitoring. Primary cross-sectional data has been collected using purposive sampling technique, through- direct/telephonic interview, emailing, meetings, seminars and FGDs with semi-structured questionnaire (using 5-point Likert-scale, ranging from 1= strongly disagree to 5= strongly agree). Qualitative data have been also gathered by informal discussion/interview conducted with community people, academia, Govt. officers, researchers, representatives of NGOs/Development partners, students and so on. Data collected from primary sources has been analysed through various analytical tools and techniques to comprehend the relationship between independent and dependent variables. Furthermore, statistical software SPSS 17 has been used to analyse the data. In this research utilization of UAVs for coastal monitoring has been considered as dependent variable and research & development (V1), interagency coordination (V2), price and import tax of UAV (V3), capacity building (V4) and technological cooperation (V5) have been considered as independent variables. This study has been conducted under the statistics of inferential analysis consisting t-test, Pearson correlation analysis and regression analysis. It has also considered one-way ANOVA test to examine the significant relationship among the variables.

## Impacts of Sea Level Rise in the Coastal Region of Bangladesh

Climate change-induced Sea Level Rise (SLR) has been a major concern for coastal and low-lying areas of the world since these areas undergoes several morpho-dynamic processes due to several geomorphological, climate change and oceanographic factors. IPCC estimated that sea level rise would be 66 cm under business-as-usual conditions by 2100 with a range of uncertainty of 13 to 110 cm. The US Space Agency and other US government agencies warned in 2022 that sea levels along the country's coastlines could rise by another 25-30cm by 2050 (World Economic Forum, 2024).

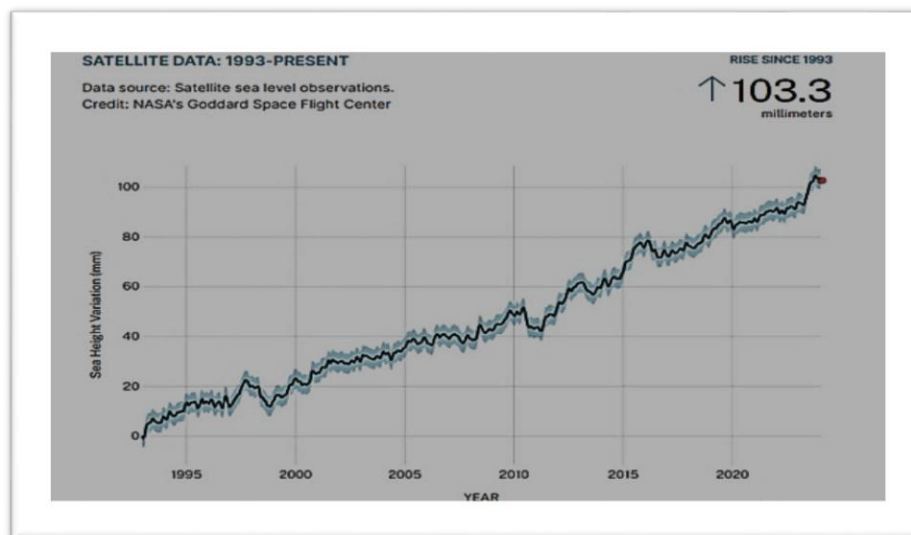
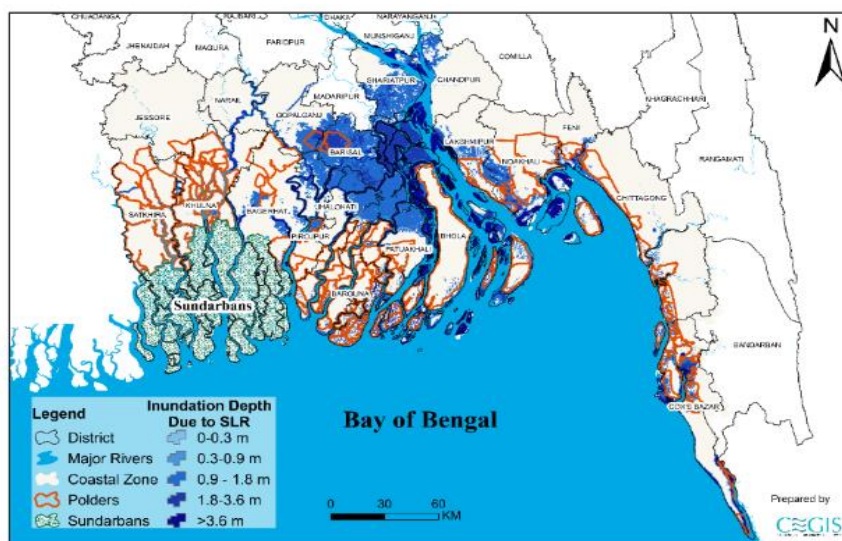


Figure 1: Global Sea Level Change (1993-2024)

Image Source: NASA

According to the Global Climate Risk Index of 2021, five of the top ten nations most affected by long-term climate-induced risks were Asian countries. Bangladesh ranked seventh in both the 2020 and 2021 reports. A considerable number of empirical studies have been carried out with respect to SLR induced impacts and associated extreme events in Bangladesh. Ahmed et al. (2020) reported that among the coastal zones of Bangladesh, the central zone is highly susceptible to erosion being influenced by the different hydro-climatic factors including sea level rise.

The higher variation of mean SLR along with varied degrees of river discharge contributes to the high rate of erosion in the country. UN High Commissioner for Human Rights and the Environmental Justice foundation stated that around 16330.6 to 25238.2 square kilometers of Bangladesh—especially around the low-lying coastal regions—will be submerged due to rising sea levels by 2050. Bangladesh may have almost 20 million internal climate migrants by 2050 – corresponding to roughly 12% of the entire population of Bangladesh with a projected 50 cm rise in sea level and the country may lose approximately 11% of its land by then.



Map 2: Potential Inundation in Bangladesh by 2050

Source: CEIGS, BoB Model 2021

Environmentalists and geologists emphasize that if the sea level rises even by 1 meter, 70% of Sundarbans will be submerged. It is estimated that each year, in communities like Khulna, Bagerhat, Barguna, Barisal, Bhola, Khulna, Jhalakati, Pirojpur, and Satkhira increased salinity, siltation, flooding, and worsening cyclones have devastated the agriculture sector, affected living and working conditions. This means Bangladesh is very vulnerable to rising sea levels due to global warming as low-lying lands will get submerged first. Climate change will further aggravate historical sea-level rise and projections for the coastal areas, affecting coastal communities, infrastructure and livelihoods (Figure 2). Climate change and SLR will have a detrimental impact on all of the forest ecosystems in Bangladesh, and the Sundarbans are likely to be the worst affected. Low lying coastal cities are at the forefront of climate change impacts, directly vulnerable to the risks of sea level rise and storms. Direct impacts will occur through the increased floods, drainage congestion and water logging, as well as further infrastructure damage during extreme events. Milliman et al. (1989) reported 1.0 cm per year sea level rise in Bangladesh. World Bank (2000) showed 10 cm, 25 cm and 1 m rise in sea level by 2020, 2050 and 2100; affecting 2%, 4% and 17.5% of total land mass respectively (Table-1). A 1m rise in sea level would submerge around 18 % of the total land area in Bangladesh (Minar, Hossain, and Science 2013). Maximum rise in the water level is observed in the South East region at the Maheshkhali which is 7.4 mm/year followed by 7.04 mm/year in the Sandwip and 5.05 mm/year in the Cox's Bazar (Nishat and Mukherjee 2013). The south-east and eastern coastal area (SEE) has an area of 13,891 sq. km and 10.93 million vulnerable people.

**Table 1: Sea Level Rise in Bangladesh and its Possible Impacts**

| <b>Year</b>           | <b>2020</b>                                              | <b>2050</b>                                                                                                                                                 | <b>2100</b>                                                                                                                                                                |
|-----------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Sea level rise</b> | 10cm                                                     | 25cm                                                                                                                                                        | 1 m (high end estimate)                                                                                                                                                    |
| <b>Land below SLR</b> | 2 % of land (2,500 km <sup>2</sup> )                     | 4 % of land (6,300 km <sup>2</sup> )                                                                                                                        | 17.5 % of land (25,000 km <sup>2</sup> ). Patuakhali, Khulna and Barisal regions will be most affected                                                                     |
| <b>Storm surge</b>    | -                                                        | 1991 cyclone happens again with a 10 % increase in intensity, wind speed increases from 225 to 248 km/h; storm surge goes from 7.1 to 8.6 m with 0.3 m SLR. | Storm surge goes from 7.4 to 9.1 m with 1 m SLR.                                                                                                                           |
| <b>Flooding</b>       | 20% increase in inundation.                              | Increase flooding in Meghna and Ganges floodplain. Monsoonal floods increase yield loss.                                                                    | Both inundation area and flood intensity will increase tremendously.                                                                                                       |
| <b>Agriculture</b>    | Inundate 0.2 Mmt. of production; < 1 % of current total. | 0.3 m SLR inundate 0.5 Mmt. of production; 2% of current total.                                                                                             | Devastating flood may cause crop failure for any year.                                                                                                                     |
| <b>Ecosystem</b>      | Inundates 15% of the Sundarbans                          | Inundates 40% of the Sundarbans.                                                                                                                            | The Sundarbans would be lost. Loss of the Sundarbans and other coastal wetlands would reduce breeding ground for many estuarine fish, which would reduce their population. |
| <b>Salinity</b>       | Increase                                                 | Increase                                                                                                                                                    | Increase                                                                                                                                                                   |

(Adapted from World Bank, 2000)

The region faces hazards similar to those in the south-western coast. It includes the major industrial areas, ports and some forests. A large percentage of households have faced damages due to cyclones (29 percent), salinity (2.5 percent) and lightning (7.2 percent) in recent years (BBS, 2022a). Average losses and damages due to disasters were BDT 17.2 billion during 2016-2021, mainly driven by climatic stresses (BBS, 2022a). Future climate change will intensify these stresses. The impact of climate change on livelihoods may propel approximately 19.9 million internal climate migrants by the 2050s, half the projected climate migrants of the entire South Asia region (NAP, 2022). In 2020, Cyclone Amphan affected more than a million people in 26 districts and caused 26 deaths. It damaged 55,667 houses, 149,000 ha of agricultural lands, 1,80,500 hatcheries, 150 km of embankments, 200 bridges and culverts, and 100 km of roads, causing a total loss of BDT 11 billion (IFRC, 2021). Future 50 cm sea-level rise combined with a SIDR/Amphan equivalent cyclonic storm surge could potentially inundate large parts (11%-12%) of the coastal area of Bangladesh (DoE, 2020).

**Utilization of UAVs for Coastal Monitoring: Global Perspective**

As the impacts of climate change continue to escalate worldwide, coastal and marine environments, especially those in Asia, bear the brunt of these alterations. However, the use of advanced technologies like drones is proving instrumental in combating these challenges. In relation to sea-level rise, the most important early measure required is to start making more detailed assessments of different physiographic regions and sub regions within and adjoining the coastal zone in order to provide a comprehensive factual basis for planning current and future development. Existing institutions for monitoring tide levels, river flow, soil and water salinity need to be strengthened. Field surveys will be needed to supplement existing information; and interpretations of satellite images must be supported by adequate ground truthing. Such surveys will need to be followed by relevant studies to identify, test and cost appropriate intervention measures for individual areas, including institutional and political measures that might be needed to implement and support identified measures. Budgets and time-frames for implementation in different areas will then need to be drawn up as well. Patently, it will be essential to engage local people in survey, studies and decisions in order to harness their local environmental knowledge that are considered necessary in both their own and the national interest. For the last couple of years, Unmanned Aerial Vehicles (UAVs) or Drone are in use of climatic research to acquire data as well as relevant information over areas under investigation in Australia and the US. The UAV is an aircraft without any human pilot on board. It can be operated either remotely, i.e. controlled by a human operator or completely autonomously i.e. by the help of on-board computer (Unmanned Aircraft System, 2016). It is basically used in that area which is inaccessible and dangerous to human beings (Tice, 1991). Originally, UAV is mainly used in military applications, in recent years it is expanding its wing in agriculture, scientific activities, and recreation and in many other applications like climatic research, marine & forest surveillance, coastal monitoring, track coastal habitat & bio-diversity, disaster risk management, rescue operations, delivering goods, aerial photography, etc. (Franke, 2015). Drones generally offer a low-cost and easy to use means of collecting high-quality geospatial data. In many countries and scenarios, drones represent the only realistic or affordable means of collecting aerial imagery: manned aircraft and usable satellite images are not options. UAV system incorporated with image, range, position sensors are capable of capturing the multispectral image low level resolution (Lucieer et al., 2014; Primicerio et al., 2012; Turner et al., 2011; Bendig et al., 2012). Drones permit disaster responders to quickly create usable, actionable maps, and to rapidly impact a disaster's effects on the coastal community.

**Significance of UAV (Unmanned Aerial Vehicle) data for Coastal Monitoring and Prospects in Bangladesh**

Unmanned Aerial Vehicles (UAVs) are emerging as transformative tools in providing high-resolution, site-specific data for monitoring and managing climate risks. Tide-gauge and satellite data (1983–2014) revealed distinct phases of sea level behaviour in Bangladesh. But UAV surveys revealed annual shoreline retreat up to 5 m in erosion hotspots. Satellite imagery (1989–2021) confirms consistent shoreline retreat. On the other hand, UAVs produced high-resolution elevation data have been used for inundation simulation. Rapid UAV deployment after storm surges (e.g., Cyclone Amphan) also helped quantify flood extent and infrastructure damage. UAV imagery can track mangrove dieback and regeneration which is crucial for ecological resilience. A comparative overview highlighting the differences between UAV data & satellite data and the unique benefits of UAV data are discussed below to understand the significance of utilization of UAVs in the coastal region of the country:

**Spatial Resolution**

UAV Data is collected through extremely high spatial resolution (up to sub-centimeter level) which is ideal for detecting fine-scale coastal features like erosion lines, dune morphology, vegetation changes, and infrastructure damage. On the other hand, Satellite Data varies by satellite; which is typically, medium to high resolution (10–30m for Sentinel, 0.3–5m for commercial satellites) that is suitable for large-scale patterns but less precise for micro-scale changes. Therefore, UAV data enables micro-level management decisions (e.g., shoreline retreat at specific points), while satellite data supports macro-level planning (e.g., sediment movement trends across regions).

**Temporal Resolution**

UAV data from coastal area can be collected on demand, as UAV can be flown whenever needed, especially after storms or tidal events. Whereas, collection of satellite data depends on satellite orbits and revisit times (e.g., Sentinel-2 revisits every 5 days), and may be obstructed by clouds. So, UAVs are valuable for emergency response, rapid assessment, and short-term coastal monitoring, especially when satellites are unavailable or ineffective due to weather.

**Cloud Penetration & Weather Dependency**

UAV can operate below clouds and in low-visibility conditions (to an extent) whereas, optical satellites are heavily affected by clouds. Radar satellites can penetrate clouds but offer lower resolution. Therefore, UAVs offer more reliable data in cloud-prone coastal regions, especially during monsoon or cyclone seasons.

**Data Accuracy and Control**

UAV can control flight plans, camera positions, and sensor types which give high accuracy and flexibility in data acquisition. But UAV can cover limited areas. On the other hand, satellite has limited control over acquisition parameters and data depends on satellite mission parameters. UAVs provide customized and highly accurate data which is essential for site-specific interventions like mangrove restoration or embankment monitoring. But, satellite can cover vast coastal regions in one pass (up to thousands of

square kilometres). So, Satellites are best for regional to global-scale coastal assessments, while UAVs are best for detailed local-scale studies.

### Application-Specific Strengths

The following table shows the comparison between strengths of UAV and Satellite application.

**Table 2: Strength of UAV and Satellite Application**

| Application                  | UAV Strength                    | Satellite Strength           |
|------------------------------|---------------------------------|------------------------------|
| Monitoring Shoreline erosion | High-detail topographic change  | Long-term trend mapping      |
| Monitoring Flood damage      | Rapid post-event mapping        | Broad impact area monitoring |
| Habitat monitoring           | Fine vegetation differentiation | Seasonal phenology           |
| Infrastructure inspection    | Close-up 3D models              | Site identification          |

There are immense prospects of utilization of UAVs for coastal monitoring in Bangladesh if proper steps are taken to overcome the existing challenges for the sustainable utilization of UAVs in Bangladesh. The geographical diversity and complexity of Bangladesh's coastal zone and the multidisciplinary nature of many of the mitigation measures identified that a comprehensive Integrated Coastal Zone Management Plan is needed, along the lines of the Dutch Delta Management Plan, with appropriate staffing to prepare, operate, monitoring and oversee it. National and Local authorities who manage the coastline and are engaged to implement national mitigation and adaptation plan need to take effective decisions on the basis of real time data. Collecting data with UAVs could lead to significant efficiencies in coastal monitoring, management and maintenance apart from improve effectiveness of erosion mitigation measures. The Civil Aviation Authority of Bangladesh (CAAB) approved a regulation for operating remotely piloted aircraft systems in 2016. From coastlines to inland flood plains, gaining a more accurate and accessible view of our environment using drones will help concerned authority and researchers to manage and adapt to environmental pressures as climate change and SLR increasingly affect Bangladesh. Modern geospatial technology is used to enhance disaster preparedness as well as response activities. UAVs can be used for data collection through coastal monitoring that assists in disaster risk reduction efforts in the country. These data can be fed into modelling systems that provide valuable insights which can assist the Government in better planning of disaster relief management as well as response services. In Bangladesh, geological surveys reveal that Bangladesh itself is lying over as well as surrounded by three fault zone topography. UAV as a tool can be used for mapping fault zone topography. This could be used to coastal management decision-making as well as record the coastal response to specific storm events. UAVs/Drones can be used for coastal and landscape mapping in Bangladesh to provide precise pictures for valuation, monitoring as well as research. Drones may play an effective role in checking illegal intrusion in the coastal zone of the country including Sundarbans, identifying illegally net fishing in the forest too. The ortho maps can help to improve forest management (Sundarbans) as well as operational planning, poaching of endangered species, unsustainable uses of forest resources, land occupancy as well as encroachment. It can also assist in tracking native species, monitoring biodiversity as well as ecological landscape features. It is very useful for coastal area & forest inventories including adaptive planning, high project customization, and rapid implementation, even under challenging weather conditions. In Bangladesh UAVs can be used to map waterlogged areas, identify the causes as well as take quick and necessary actions to free submerged roads from waterlogging in coastal areas. During flash flooding, water levels rise and fall rapidly with little or no warning. However, drone technology can resolve this drastic problem. With the application of high-resolution infrared cameras, health of habitat in the coastal areas can be assessed and adequate emergency measures can be undertaken as well. A smart coastal environment monitoring (Smart EM) method can be implemented in Bangladesh by using an Unmanned Aerial Vehicle (UAV) to collect and process the data. UAV-based data acquisition is an effective solution for retrieving sensor data, even from inaccessible locations. In Bangladesh UAVs can be used to map waterlogged areas, identify the causes as well as take quick and necessary actions to free submerged roads from waterlogging in coastal areas. During flash flooding, water levels rise and fall rapidly with little or no warning. However, drone technology can resolve this drastic problem. With the application of high-resolution infrared cameras, health of habitat in the coastal areas can be assessed and adequate emergency measures can be undertaken as well. A smart coastal environment monitoring (Smart EM) method can be implemented in Bangladesh by using an Unmanned Aerial Vehicle (UAV) to collect and process the data. UAV-based data acquisition is an effective solution for retrieving sensor data, even from inaccessible locations.

### Data Analysis and Findings of the Study

#### Qualitative Approach

The qualitative component of this study was designed to supplement and validate the quantitative data. It helped contextualize the findings and interpret them from a socio-environmental perspective. During field visits and data collection, researcher and her data enumerators observed and recorded interactions, environmental conditions, and local practices related to shoreline protection and use of resources. There was a demand for community participation in data collection and interpretation to ensure local relevance and trust. Local residents reported accelerated shoreline erosion, especially after cyclones or monsoon seasons. Several families in Kutubdia described how their homes had to be relocated inland in the last 5–10 years. Increased tidal flooding and salinity intrusion

were cited as key threats to agriculture and drinking water availability. Communities used traditional methods like bamboo fencing and mangrove planting to resist erosion. A move from agriculture to fishing and day labor was noted, as land became unusable or submerged. It has been observed through focus group discussion that most stakeholders welcomed UAV monitoring for its potential accuracy, some expressed concern about data access, transparency, and how it would translate into policy change. Local stakeholders made doubt on the utilization of UAV data for the change of their living standards and misery. Interviews with local officials revealed gaps in inter-agency coordination, lack of real-time data, and budget constraints in implementing UAV-based monitoring on a large scale. The following table shows the summary of insights of qualitative data.

**Table 3: Qualitative Data Insights**

| Theme                                  | Key Insights                                                              | Illustrative Quotes                                                                                             | Connection to UAV Findings                                                         |
|----------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Coastal Erosion & Land Loss            | Recurrent loss of land, homes, and infrastructure along the coast         | <i>"Local residents had to shift their house frequently in the last ten years."</i> — Resident, Kutubdia        | UAV imagery can confirm shoreline retreat and expose land area loss.               |
| Flooding and Salinity Intrusion        | Increased flooding and soil salinity affecting crops and water sources    | <i>"We can't grow paddy like before; saltwater enters the fields during high tide."</i> — Farmer, Chakaria      | UAV can support NDVI and land use maps can show crop degradation and soil wetness. |
| Livelihood Shift                       | Shift from farming to fishing or day labor due to loss of arable land     | <i>"Fishing is now our only option to lead life; the land is no longer fertile."</i> — Local farmer in Kutubdia | UAV can observe transformation from agricultural to aquaculture zones.             |
| Mangrove Loss and Environmental Change | Mangrove degradation due to human activity and weak enforcement           | <i>"People are cutting trees at night; nobody stops them."</i> — Local NGO worker                               | UAV-detects reduction in vegetative cover, especially near settlements.            |
| Attitudes Toward UAV Monitoring        | Mixed reactions: hope for precision but concern over exclusion or misuse  | <i>"The flying cameras are good, but who sees the data and its utilization for us?"</i> — Fisherman, Teknaf     | Emphasizes need for participatory mapping and public access to UAV findings.       |
| Community Adaptation Strategies        | Use of local materials (e.g., bamboo, sandbags), informal warning systems | <i>"We've made bamboo fences ourselves to stop waves."</i> — Elderly community member, Kutubdia                 | UAV can capture the images of handmade barriers and temporary embankments.         |
| Institutional Limitations              | Lack of coordination, data sharing, and training in local agencies        | <i>"We need training and proper guidelines to use drone data."</i> — Upazila officer of Cox's Bazar             | Highlights gap between data collection and actual use in decision-making.          |

The qualitative data has enriched the study by embedding human experiences, providing a holistic understanding of coastal intricacies in Bangladesh. It emphasized the importance of integrating community knowledge with UAV utilization for effective, sustainable coastal monitoring and policy development.

## Quantitative Approach

UAVs are crucial for local-scale, high-precision monitoring the impacts of sea level rise. The integration with traditional remote sensing and field data offers a robust solution for coastal management in Bangladesh and beyond. There is ample opportunity to utilize UAVs for coastal monitoring in Bangladesh and the stakeholders are also realizing its significance as well. During field visits the respondents and other stakeholders mentioned about the factors that directly affect the utilization of UAVs for coastal monitoring. To examine how different factors (independent variables) affect the extent of UAV utilization for coastal monitoring in Bangladesh, primary data has been collected from 350 respondents to identify the major determinants that affect the utilization of UAVs for coastal monitoring in Bangladesh.

**H<sub>0</sub> (Null Hypothesis):** There is no significant impact of independent variables upon UAV utilization.

**H<sub>1</sub> (Alternative Hypothesis):** There is significant impact of independent variables upon UAV utilization.

**Pearson Correlation Analysis:** Pearson correlation is used to determine the relationship between any two variable or more in which they vary across a period, Correlation can vary from +1 to -1, where values close to +1 are highly correlated while values close -1 are lowly correlated.

**Table 4: Pearson Correlation Analysis**

|                     | V1      | V2      | V3       | V4      | V5      |
|---------------------|---------|---------|----------|---------|---------|
| Pearson Correlation | 0.427** | 0.497** | -0.209** | 0.345** | 0.552** |
| Sig. (2 -tailed)    | 0.000   | 0.000   | 0.000    | 0.000   | 0.000   |
| N                   | 350     | 350     | 350      | 350     | 350     |

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

In this research, the above table of Pearson correlation analysis shows that V5 technological cooperation has the highest and positive correlation with dependent variable ( $p=0.552$ ) while V2 interagency coordination and V1 research and development have almost average and positive correlation of ( $p=0.497$ ) and ( $p=0.427$ ) respectively. V4 capacity building has a p value 0.345 with positive correlation with dependent variable, but V3, price and import tax of UAVs has a p value -0.209 which shows negative relationship with the dependent variable. Overall, the Pearson correlation result shows that all the independent variables are more or less positively correlated with dependent variable except V3.

**Table 5: Regression F Values**

| Model |            | Sum of Squares | Degree of Freedom | Mean Square | F Value | Sig-(2 tailed) |
|-------|------------|----------------|-------------------|-------------|---------|----------------|
| 1     | Regression | 29.916         | 5                 | 5.983       | 49.265  | .000b**        |
|       | Residual   | 41.778         | 344               | .121        |         |                |
|       | Total      | 71.694         | 349               |             |         |                |

- Dependent Variable: Utilization of UAVs for Coastal Monitoring
- Predictors: (Constant), Research & Development, Interagency Coordination, Price and Import Tax of UAVs, Capacity Building and Technological Cooperation.
- Significant at 5% level of confidence.

The value of F test in this model is 49.2651, which indicates high F value, But the p value .000b (b= predictors: Constant) of all the independent variable are significant at 5% level of confidence. As a result, all the null hypotheses are rejected and alternate hypotheses are accepted. So, there are significant relationship between dependent and independent variables.

**Table 6: ANOVA One-way T test**

| Predictors                  | F Value | Utilization of UAVs:<br>Sig. (2 tailed) |
|-----------------------------|---------|-----------------------------------------|
| Research & Development      | 9.261   | .000**                                  |
| Interagency Coordination    | 10.360  | .000**                                  |
| Price and Import Tax of UAV | 3.645   | .000**                                  |
| Capacity Building           | 4.047   | .000**                                  |
| Technological Cooperation   | 13.607  | .000**                                  |

\*\*Significant at 5% level of confidence

Based on the findings of ANOVA one-way T test, the p value of each five independent variable are 0.000 (less than  $\alpha=0.05$ ) which represents significant relationship between dependent and independent variables. All the independent variables have direct impact upon dependent variable. It has been realized from the research result that if research and development concerning UAV increases, then scope of utilization of UAVs for coastal monitoring in Bangladesh will be increased, same as, if interagency coordination increases for the development and uses of UAVs for coastal monitoring then scope of utilization of UAVs will be increased. Further if capacity building and technological cooperation locally and globally enhances, then utilization of UAVs for coastal monitoring in the country will also be enhanced. Therefore, it is measured by the data analysis that if the price and import tax of UAVs or relevant equipment for building a UAV increases then scope of utilization of UAVs for coastal monitoring in the country will decrease as in this research, data shows that there is a negative relationship between price and import tax of UAVs and utilization of UAVs for coastal monitoring.

### **Challenges and Way Forward**

Most experts agree that climate change is one of the biggest challenges in recent era. Sea level rise is one of the symptoms of the phenomenon. Managing coastal and ocean activities is a big challenge for the days ahead. The use of drone technology can go a long way in the effort to protect coastal environment around the world. There are several challenges to the successful implementation of UAVs in Bangladesh for coastal monitoring and disaster management, such as: high initial cost, import tax and requirement of quality software; lack of clarity around how drone data influences decision-making; lack of institutional buy-in or support; cost of hiring drone services; limited technical expertise and availability of trained personnel; technical and environmental constraints (weather dependency); data privacy and security; flight time and range; legal aspects and interference with the airspace; lack of research and capacity building; limited interagency coordination; lack of technological cooperation etc. For the successful utilization of UAVs in Bangladesh for coastal monitoring and disaster management, the existing challenges need to be addressed with adequate measures. Although there is no lack of laws, policies and strategies in Bangladesh and each and every law is satisfactory, but the problem lies with the comprehensiveness and that most of the laws, as adopted, cannot reach the phase of implementation. The Territorial Waters and Maritime Zones Act, 1974 is the first law in independent Bangladesh that governs the coastal issue, especially delimiting maritime territory. In South Asia, Bangladesh is a pioneer in initiating the integrated concept for coastal management in this region. It is apparent that there have been a number of sectoral laws, policies, plans and action programs related to marine management and development in Bangladesh and various institutions and organizations have been created by law to perform specific tasks. But lack of harmonization of these instruments and lack of interactions among different sector organs of the government, fail to bring a comprehensive, integrated and holistic view into place for improved management. Inadequate and discontinuous flow of resources (human, technical and financial) is another barrier to ensuring long-term improved management in the coastal areas of Bangladesh. Harmonization of different national & international policies, and making them consistent with one another to produce one comprehensive single document, will be a big challenge and there is no way to escape it if sustainable development is desired. To monitor and manage coastal and marine resources and environment utilizing drone data, the following recommendations can be taken into consideration and incorporated into the policy framework;

Research and development are crucial for the expansion of UAV industry in Bangladesh. To utilize the drone technology adequately for coastal monitoring in Bangladesh, concerned organizations can undertake research projects collaboratively.

Integration, harmonization and consistency of strategies for coastal monitoring is required to turn them into a single comprehensive policy document. Interagency coordination can be strengthened by establishing a lead agency and placing it at the highest level of government to work as the catalyst to translate the programs into action.

Facilities and capacities in the existing institutions and organizations must be increased to turn their weaknesses into strengths and capacity building of the human resources who are engaged in coastal management must be given top priority.

There should be a long-term sustainable funding mechanism through Public Private Partnership (PPP). Technical capacities must be enhanced with global technological cooperation by providing appropriate training for operating UAVs properly. Financial support could be provided through government incentives, foreign investment, and public-private partnerships, ensuring Industry-University collaboration, capacity building in relevant research projects. Drone industry in Bangladesh may flourish if Govt. rebate tax for the import of UAV/drone or necessary equipment.

ICT services need to be promoted by developing effective and need-based ICT tools to translate and transform drone-based data and climate information services among value chain actors, for sustainable coastal risk management.

A practical implementation framework for coastal monitoring could be developed that coordinates effective institutional arrangements, locally led as well as socially inclusive in an integrated manner.

Global historical success stories regarding the utilization of UAVs for coastal monitoring must be analysed for developing country-specific need-based strategies and action plan. Scientific and traditional knowledge must be combined with past experiences to develop a baseline on which management can be established and at the same time a strong monitoring and evaluation mechanism should be developed and ensured.

Proper planning for regional initiatives, bi-lateral and multi-lateral agreements which are now in place could be strengthened, and implemented to deal with trans-boundary issues surrounding Bay of Bengal and find the further scope of cooperation for successful utilization of UAVs for coastal monitoring in the region.

### **III. Conclusion**

Availability of precise and reliable 'Drone data' would help immensely in launching effective coastal monitoring and coastal resources management plans in our country as well as its appropriate implementations. At present, Drones are used at a very limited scale in Bangladesh. Even then, the authorities have imposed various restrictions to regulate Drone flights in the country. Small and medium-size drones are mostly used for conducting atmospheric research including studies on atmospheric composition, pollution, vertical aerosol distribution, as well as surface temperatures. The researcher could be able to motivate the policymakers for undertaking further actions to address the underscored challenges for exploring utilization of UAVs in Bangladesh for coastal monitoring. Mass awareness could be built up among people regarding UAV uses as well as concerned policy. Besides these, the

concerned authority could take assistance from foreign experts to build up UAV industry in Bangladesh. Civil Aviation Authority of Bangladesh could use advanced technologies, navigation aids, and modern equipment such as surveillance radar (TCAS) Traffic collision avoidance systems to avoid mid-air collision as well as maintain safety concerns. Using drones for geographical research can increase the accuracy of field data and save time as well. Moreover, instead of focusing on regulations restricting UAV usage, it's time for the authorities in Bangladesh to take a proactive role in catalysing the growth of UAV start-ups for service innovation, through liberal regulations, research, and development (R&D) supports as well as lead usages. The fact that UAVs will be increasingly utilized in the future but for now, this study has discovered the areas on which we need to focus and pay further attention.

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