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Impact of Salinity Intrusion on Coastal Agriculture and Farmer's Livelihoods in Bangladesh

Md. Anowarul Islam[1*]

[1]Department of Geography and Environment, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh.

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The main objective of this study is to explore the major impacts of salinity intrusion on coastal agriculture and farmer's livelihoods in Bangladesh. The study has attempted to identify some effective measures for the sustainability of coastal agriculture. The study was conducted based on both primary and secondary data during 2010-2020. To collect primary data, a total of 150 respondents out of 240 households were randomly interviewed and samples are drawn proportionately from study sites. Descriptive and inferential statistics have been done to analyze data. The ArcGIS mapping tool was adopted to represent the spatio-temporal change of saline area. It reveals that due to high salinity intrusion the coastal agriculture has already experienced noticeable adverse impacts especially in increasing rate of salinity, loss in cultivable land and production. Shrimp farming with brackish water and tidal inundation are explored as the main causes for salinity intrusion. In study sites, the level of salinity in 2020 is much stronger than in 2010. It reveals that due to strong salinity in agricultural land the farmer's are suffering from low income, unemployment, scarcity in irrigation and freshwater. It was identified that the planned shrimp culture, management of the embankment, cultivation of saline tolerant crops and raising public awareness will be the possible measures to control the intrusion of salinity. Therefore, it is expected that the evaluation of the revealed impacts of salinity intrusions and the explored measures will be effective to ensure the sustainability of coastal agriculture in Bangladesh.

Keywords: Agriculture; salinity; farmer's livelihood; sustainability; coast; Bangladesh.

**Corresponding author: E-mail: anowar.ru@gmail.com;*

1. INTRODUCTION

The low-lying coastal area of Bangladesh as a main agricultural zone of the country is highly vulnerable to the adverse impact of salinity intrusion [1]. The total area of Bangladesh is 147,570 km^2. The coastal area covers about 20% of the country and out of 2.85 million hectares of the coastal and offshore areas about 0.83 million hectares are arable land, which cover over 30% of the country's total cultivable land [2]. The cultivable areas in coastal districts are affected with varying degrees of salinity [3]. It has been recognized that in the coastal zone about 8,142 km^2 (5.5% of the country) land is saline affected and that this is increasing at the rate of 146 km^2 per year [4]. The high salinity intrusion in coastal agricultural land causes reduction in crop production, which is roughly 50% of the country's average [5].

The active deltaic flood plain of the western coastal region of Bangladesh contributes to almost half of the total coastal agricultural production [6]. Recent years this western coastal region has faced the adverse impacts of salinity intrusion in its agriculture [7]. The global climate change induced sea level rise, low-lying topography, less freshwater discharge from upstream are mentioned as large scale factors for intrusion of salinity in the western coastal region of Bangladesh [8]. Moreover, the severe cyclone induced high surges in recent years accelerates the intrusion of saline water into the coast [9]. The intrusion of strong salinity causes an unfavorable environment and hydrological situation that restrict normal crop production throughout the year [10]. The increasing crop failure every year is becoming a threat to ensure the food security of the country [11]. The high intrusion of salinity causes reduction in cultivable land and production. The livelihoods of the peoples who directly depends on agriculture are highly vulnerable due to the intrusion of strong salinity into their agricultural land [12].

Since the effects of strong and rapid intrusion of salinity into agricultural land enhances the total vulnerability of this region. The effect of salinity received very little attention in the past. The gradual loss in agricultural land and production with increasing poverty of the coastal people raises a national concern in recent years [13]. Although the effects of salinity on different socio-economic aspects in the context of rising sea level along the coast has been studied earlier, the local level impact of salinity on coastal agriculture in Bangladesh remains unknown. Therefore, it is important to study the major causes and impact areas of salinity intrusion on coastal agriculture in Bangladesh. In addition, it is necessary to explore the major vulnerabilities of the people who directly depend on agriculture and to find out some possible effective measures to reduce those vulnerabilities. Hence, the purpose of this study is to investigate the major causes and impacts of salinity intrusion on coastal agriculture in Bangladesh. It is also an aim of this study to explore the potential measures that will be effective to reduce the vulnerabilities of coastal agriculture in Bangladesh.

2. MATERIALS AND METHODS

The present study was conducted in the south-western coastal region of Bangladesh. The Shyamnagar Upazila of the south-western coast was selected as a study area regarding its locational importance and highly vulnerable agriculture due to the impacts of salinity intrusion. The 12 unions of Shyamnagar Upazila were chosen as study sites (Fig. 1).

The methodology of this study started systematically with problem identification and ended by explaining the impacts of salinity intrusion on coastal agriculture with identifying possible measures to reduce the impacts. The primary data was collected through a questionnaire survey in selected 30 villages covering 12 unions and the respondents were selected through random sampling. An actual sample size of 150 from total 240 households was adopted with a 5% significance level. Samples were drawn proportionately from 12 unions. The sample size was determined using the following formula [14]:

$$n = N/ (1+ Ne^2)$$
$$= 240/ (1+240\times0.05\times 0.05)$$
$$= 150$$

where,

n = Sample size
N = Population size (240)
e = Level of significance (0.05)

A structured questionnaire was used to collect the primary data through face-to-face interviews, direct observations, household survey and as well as via focus group discussions. The focus group discussion was only conducted in Gabura, Koikhali, and Atulia. The related and available secondary data are also used for the period of

2010-2020. Both descriptive (frequency, averages, percentiles, range, etc.) and inferential statistics (pie chart, bar diagram, chi-square, etc.) are used to analyze the data. The salinity data of Soil Resource Development Institute [15] and the data for cultivable land and production from the Department of Agricultural Extension [16] was used. The descriptive and inferential statistics with proper analytical tools were adopted to analyze the data. The ArcGIS mapping tool was incorporated to represent the spatio-temporal change of salinity affected areas. Finally, the following chi-square (χ^2) the test was performed to assess the significance of the explored impacts of salinity intrusion and measures to reduce the vulnerabilities of agriculture.

$$\chi^2 = \frac{\Sigma(O-E)^2}{E^2} \quad \text{(ii)}$$

Here, O = The observed number of respondents, E = The expected number of respondents

3. RESULTS

3.1 Intrusion of Salinity

Shyamnagar Upazila faces a noticeable increase in salinity during 2010 to 2020 (Fig. 2). Mainly the high intrusion of salinity was started in this area in 2009 after the super cyclone *Aila*. Salinity was measured in terms of the electrical conductivity (EC) of the saline water. Before cyclone *Aila* the strong EC (12.1-16.0 dS/m) appeared only over the lower areas of the Shyamnagar Upazila. The cyclone *Aila* generates high surges along the coast that causes a rapid increase in very strong EC (>16 dS/m) over the maximum areas of the study sites. The faster and higher increase in severe EC (around 28 dS/m) in 2019 is a result of high surges from the super cyclone of *Fani* and *Bulbul*. Following the cyclones *Fani* and *Bulbul* another super cyclone *Amphan* in 2020 also causes a devastating increase in salinity over the study sites.

The spatio-temporal change of the salinity intrusion over the unions of Shyamnagar Upazila represents that there is a large increase in saline area during 2010 to 2020 (Fig. 3). In 2010, among the 12 unions only the Gabura, Munshiganj, and Koikhali were affected by the very strong level of EC (>16 dS/m) and the others with moderate EC (8-12 dS/m). But in 2020, it denotes that there is no moderate saline area and almost all the moderate saline area was affected with very strong salinity except Bhurulia and Kashimari.

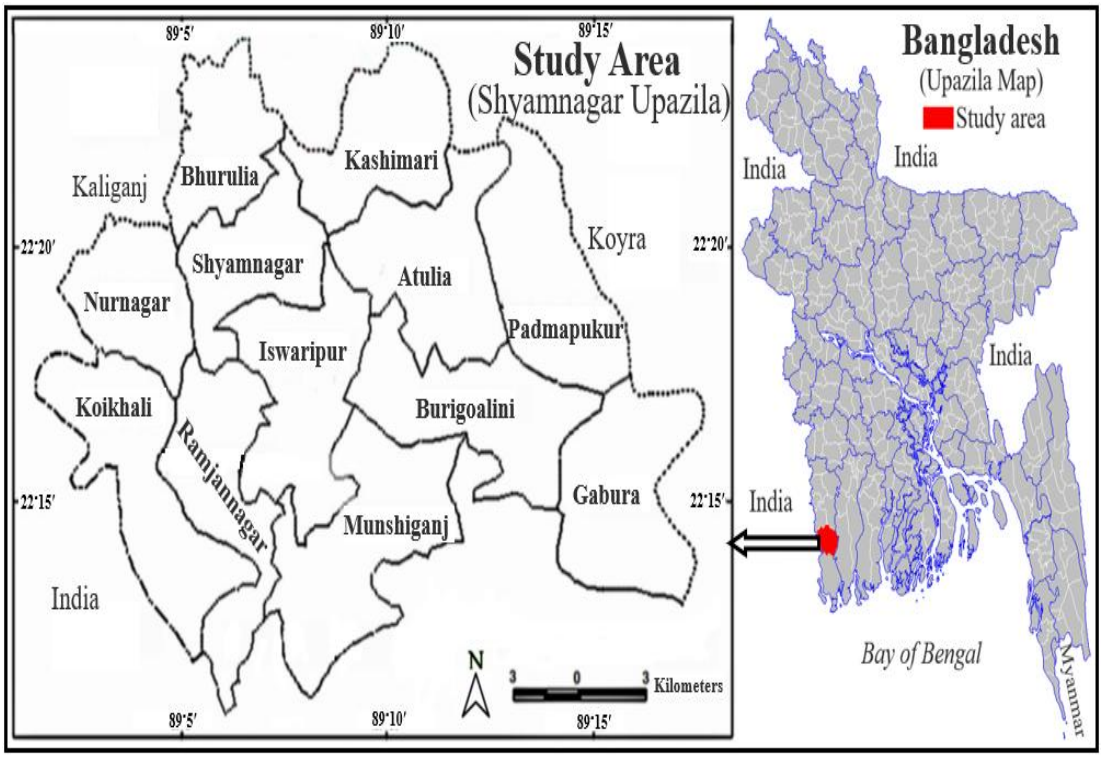

Fig. 1. The map of the study area (left: unions of Shyamnagar Upazila)

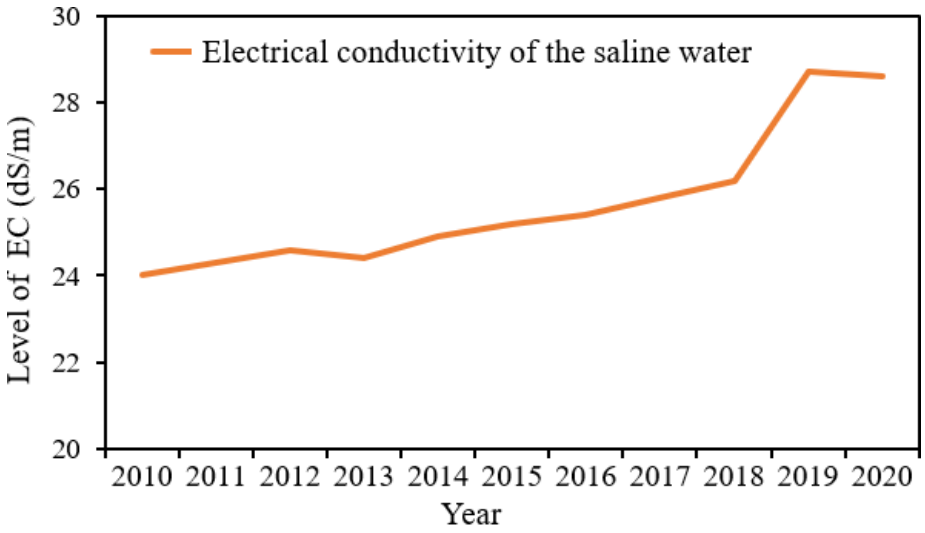

Fig. 2. The time series of the increasing trend of electrical conductivity (orange line) over the study area during 2010-2020

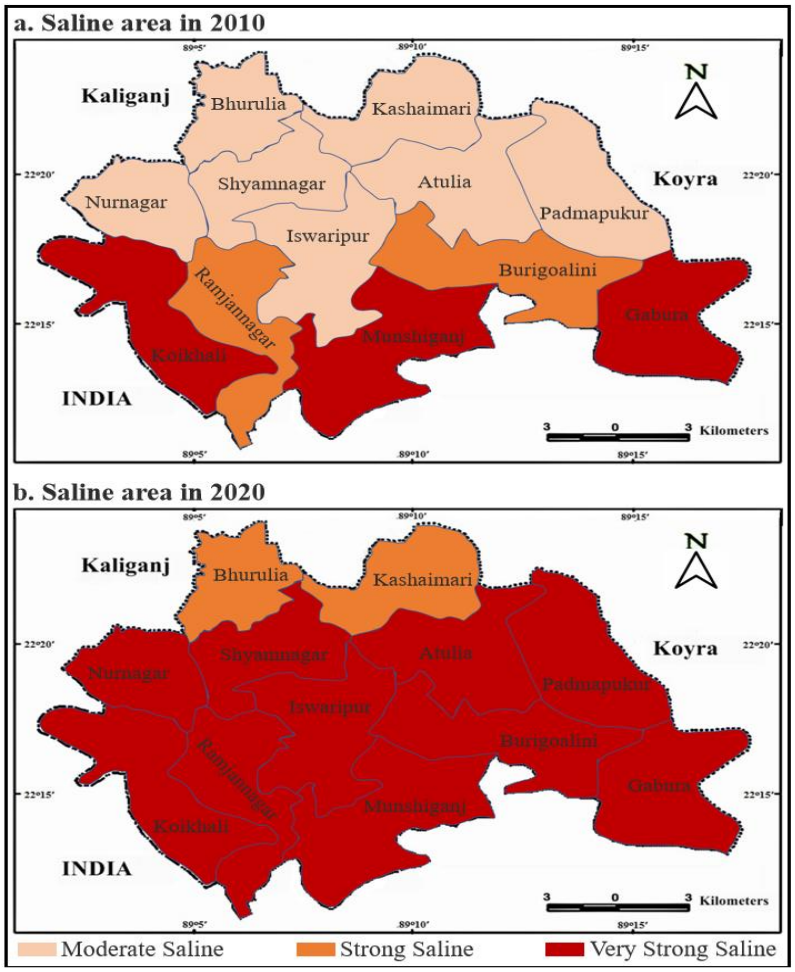

Fig. 3. The upper map (a) represents the level of salinity in the selected unions of Shyamnagar Upazila in 2010. The lower map (b) is same as (a) but for 2020. The light orange, orange, and red color represents the moderate, strong, and very strong salinity, respectively

The inhabitants of these coastal study sites also mentioned that there is an outbreak in salinity during 2010 to 2020 (Fig. 4). About more than 90% of the respondents believe that there is rapid increase of salinity from 2010 to 2020 for almost all the selected unions except Bhurulia and Kashimari. The people's perception of lower salinity (<75%) increase for Bhurulia and Kashimari are very consistent with the distribution of salinity among the unions in Fig. 3, that may relate to their location. The people's perception represents that increase in salinity during this decade (2010-2020) is almost double for Atulia, Iswaripur, Nurnagar, Padmapukur, and Shyamnagar union and that is consistent with their spatial distribution of salinity in Fig. 3.

The rapid increase of very strong salinity in 2020 (Fig. 3) was evaluated through the people's opinion in the studied unions (Fig. 5). Around 70% of the respondents think that there is high increase in salinity level for every union except Bhurulia and Kashimari. For Bhurulia and Kashimari it shows that there is moderate increase in salinity level, which is supported with their spatial distribution of salinity in Fig. 3.

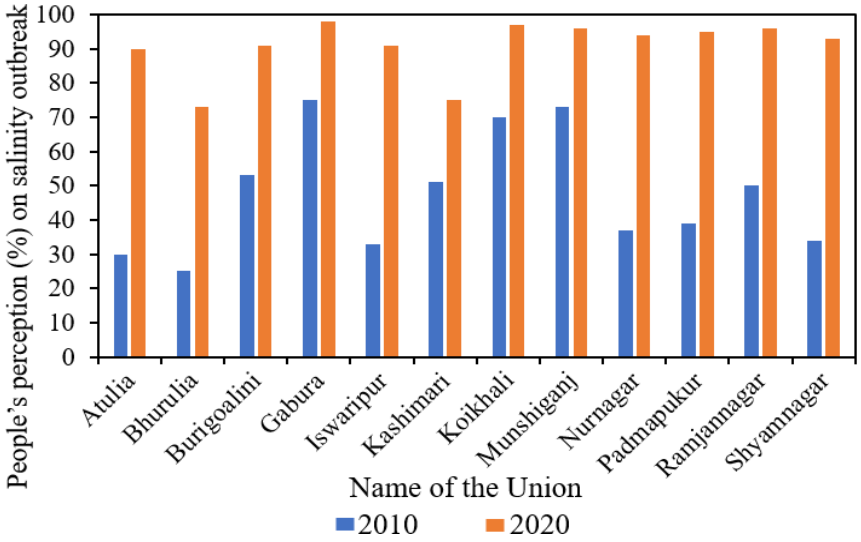

Fig. 4. People's perception on the trend of salinity outbreak from 2010 to 2020 for each of the studied unions; The blue bar represents the people's perception in 2010 and orange for 2020

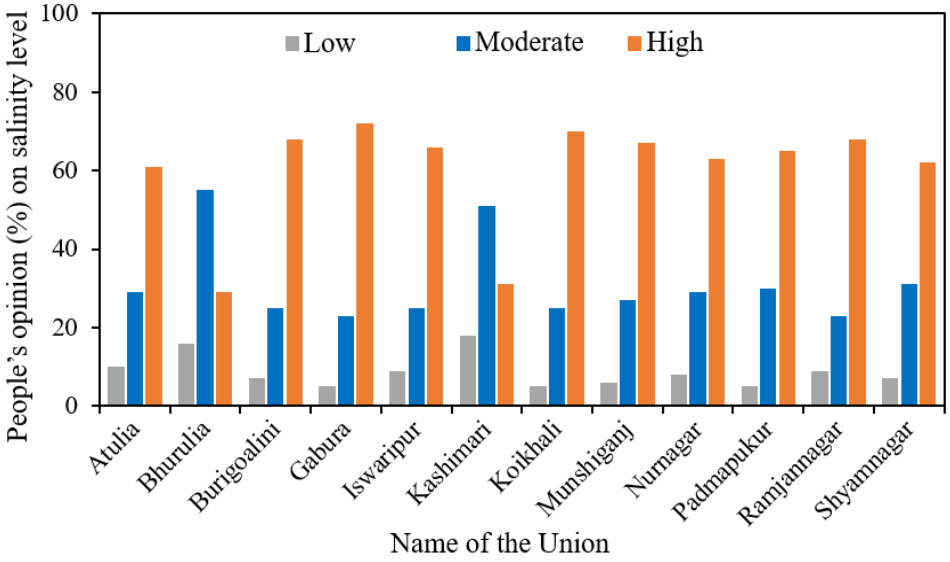

Fig. 5. People's opinion on salinity levels for each of the studied unions; The gray, blue, and orange bars represent the low, moderate, and high salinity, respectively

3.2 Causes of Salinity Intrusion

The people of the study sites mentioned that the shrimp culture with brackish water (43.33%) and tidal water inundation (39.33%) are two main causes for salinity intrusion in agricultural land in this coastal area (Fig. 6). It shows that the shrimp culture with brackish water and tidal water inundation are responsible for more than 80% of the saline water intrusion in this area. The contribution of nearness to the sea (12.67%) and riverbank erosion (4.67%) for intrusion of salinity are not so significant, it may relate to the geographical characteristics of this region. It denotes that the human activities for shrimp farming and global climate change induced tidal inundation enhance the intrusion of salinity in coastal areas. It argues that human activities for proper management of shrimp culture and actions to reduce the effect of climate change can help to minimize the impact of salinity intrusion in coastal agriculture.

3.3 Impacts of Salinity Intrusion

Due to the high intrusion of salinity, there is a rapid increase of saline affected area, diversely the amount of net cropped area and production is decreasing gradually following the increase of saline affected area during 2010-2020 (Fig. 7). It represents that during this decade (2010-2020) around 4,000 hectares of land affected by salinity and at the same time there is a loss in net cropped area around for 3,000 hectares. The rest 1,000 hectares (4,000 hectare of saline land – 3000 hectares of net cropped area) of saline land may relates to the non-agriculture area. Interestingly, it shows that there is a reduction in crop production following the decrease in net cropped area due to the rapid increase of saline area. There is loss in crop production for around 2,000 metric tons in the study area during 2010-2020. It denotes that the high intrusion of salinity decreases the cropped area and production that is a major threat for the sustainability of coastal agriculture and food security of the people.

This study also explores some major impacts of salinity intrusion through the evaluation of the people's perception from focus group discussion (Table 1). Around 34.7% of the respondents mentioned the loss in agricultural land and production as the main impacts of salinity intrusion in this area. Around 29% and 24.8% of the respondents identified the scarcity in irrigation/drinking water and extinction of freshwater biodiversity as another two alarming impacts of salinity intrusion in this area, respectively. The unemployment in agriculture as an impact of salinity intrusion was mentioned by 11.6% of the respondents. The high statistical significance (χ^2= 0.95) of the explored impacts indicates their high relevance to consider them as major threats for coastal agriculture.

3.4 Vulnerability of the Farmer's

The people's perception on the major impacts of salinity intrusion on farmer's livelihood was evaluated (Fig. 8). It shows that the low income (48%) occupied as the main vulnerable sector for the farmer's livelihood. People think that around 30% of the farmer's have changed their occupation from agriculture to other activities. Around 12% of the farmer's land is now fallow land and 7% of the farmer's homestead land are unfavorable for housing due to the adverse impact of salinity. The migration of the farmer's to other areas, becoming landless, and day laborer sare the other impacts of salinity intrusion on farmer's livelihood in this area.

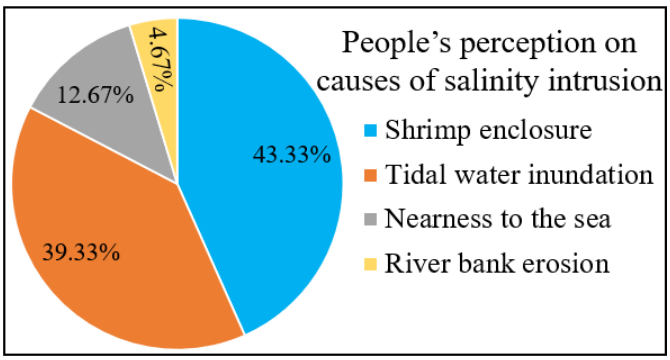

Fig. 6. The pie chart for people's perception on the causes of salinity intrusion in the study area; Each color represents the cause of salinity intrusion and percentages denotes their contribution

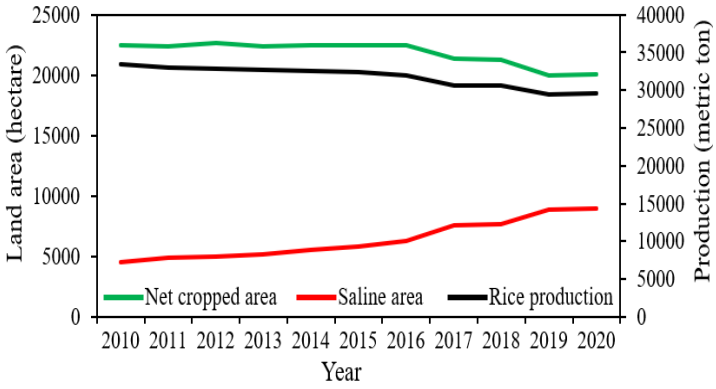

Fig. 7. The time series for net cropped area (green line), saline area (red line), and rice production (black line) during 2010-2020 in the studied unions of Shyamnagar Upazila

Table 1. People's opinion for major impact areas of salinity intrusion through focus-group discussion; Three highly vulnerable unions were selected for focus-group discussion

Impacts of salinity intrusion	Unions and people's response (%)			Total
	Gabura	Koikhali	Atulia	
Loss in agricultural land and production	17.8	9.9	6.9	34.7
Scarcity in irrigation and drinking water	14.9	8.6	5.6	29.0
Extinction of freshwater biodiversity	12.9	7.9	4.0	24.8
Unemployment	5.0	4.3	2.3	11.6
Total	50.5	30.7	18.8	100

Chi-square (χ^2) Test: Significance value = 0.95 with degree of freedom = 6

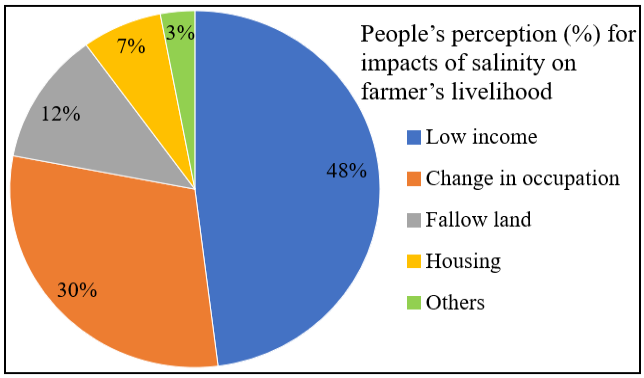

Fig. 8. The pie chart for people's perception on the major vulnerabilities of the farmers due to the impact of salinity intrusion; Each color represents the major vulnerabilities and percentages denote their contribution

Table 2. People's opinion for the measures to reduce the vulnerabilities of coastal agriculture The measures were obtained through focus-group discussion from 3 highly vulnerable unions

Measures to reduce the impact of salinity intrusion	Unions and people's response (%)			Total
	Gabura	Koikhali	Atulia	
Proper management of shrimp culture with brackish water	16.5	9.9	5.9	32.3
Development of embankment and sluice gate	13.9	9.2	5.6	28.7
Innovation and cultivation of saline tolerant crop varieties	10.2	6.6	4	20.8
Raising public awareness	9.9	5	3.3	18.2
Total	50.5	30.7	18.8	100

Chi-square (χ^2) Test: Significance value = 0.99 with degree of freedom = 6

4. DISCUSSIONS

Regarding the mentioned impacts of salinity intrusion on agriculture in the results section here a discussion was added on some explored measures to reduce those impacts. This study explores some effective measures through focus group discussion of the people to reduce the impacts on salinity intrusion into agricultural land (Table 2). In the result section it was revealed that the shrimp culture with brackish water and tidal water inundation are the main causes of salinity intrusion. Interestingly, a majority of the people (32.3%) believe that proper management of shrimp culture with brackish water is an important measure to reduce the impact of salinity intrusion. Around 28.7% people's think that the proper development of embankment and sluice gate is needed to control the tidal water inundation. The high statistical significance (χ^2= 0.99) of the explored measures denotes their high importance to consider them as key measures to reduce the impacts of salinity intrusion. Around 20.8% and 18.2% of the people's mentioned the innovation and cultivation of saline tolerant crop varieties and raising public awareness as other two important measures to reduce the impact of salinity intrusion, respectively. It is expected that the explored measures will be effective to reduce the impacts of salinity intrusion from coastal agriculture in Bangladesh.

5. CONCLUSIONS

This is a pioneer study to investigate the impacts of salinity intrusion on agriculture focusing on a highly vulnerable and marginal coastal region in Bangladesh. The study has importance for direct consideration and evaluation of the marginal people's perception on the impacts of salinity intrusion. It reveals that the salinity is increasing rapidly and now the level of salinity is very strong over the study sites. Human activity induced shrimp farming with brackish water and global climate induced tidal water inundation are identified as main causes of salinity intrusion in this area. The high intrusion of salinity decreases the amount of cultivable land and production. The people are suffering from freshwater crisis for irrigation and drinking and the biodiversity of this area are now in risk. The farmer's are highly vulnerable with low income and unemployment due to the impacts of salinity on agriculture. The explored measures of this study to reduce the impacts of salinity intrusion on agriculture will be effective to ensure the sustainability of coastal agriculture in Bangladesh.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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