Original Research Article

Recycling Selected Wetlands' Sediments for a Vegetable Crop Cultivation in Terrestrial Ecosystem of a Humid Region

ABSTRACT

This study aimed to evaluate the selected wetlands' sediments regarding physicochemical attributes including heavy metals (HMs), and their potentiality to be used in crop cultivation with or without mixing with different generic farmers' field soils in the upland. Forty geo-referenced sediment samples were collected from each study site (n=3), and mixed to get three separate composite samples for mineral nutrients, HM analyses and experimentation. Two pot experiments were conducted following Completely Randomized Design (CRD) with three replicates using farmers' field soils (FFS) Gleysols and Cambisols to grow amaranth. The treatments were: T_0: FFS; T_1: FFS + wetland sediment of hilly area I (1:1); T_2: FFS + wetland sediment of hilly area II (1:1); T_3: FFS + wetland sediment of a floodplain area (1:1); T_4: wetland sediment of hilly area I; T_5: wetland sediment of hilly area II; T_6: wetland sediment of a floodplain area.Regarding nutrient elements, exchangeable K, extractable P, Ca, and Zn were observed higher in wetland sediment of hilly area II except organic carbon (OC). Only Cd, Pb, and Ni were individually found higher than the maximum permissible addition for all wetland sediments, but all HMs collectively posed no "ecological risk". The highest values of theplant growth index of amaranth were observed for T_5 treatment. Moreover, the highest total fresh and dry biomasses were found in T_5 treatment. The highest nutrient uptake was observed in T_5 treatment for the most of nutrients. Studied wetlands' soil materials, OC, and nutrients could be used to benefit upland crop cultivation.

KEYWORDS:Sediment, heavy metals, Gleysols, Cambisols, and nutrient uptake.

INTRODUCTION

Wetlands are the lands that remainunder water either permanently for years or decades, or temporarily in seasons of a year. A wetland possesses a distinct ecosystem that serves as a home for diverse plant and animal species (www.wikipedia.org).Wetlands vary greatly due to local and regional differences in natural (soil, topography, climate, hydrology, water chemistry, vegetation etc.) and anthropogenic (human interference) factors, and they are broadly categorized as 'tidal' and 'non-tidal (inland)' wetlands (www.epa.gov).Water in wetlands is being threatened quantitatively and qualitatively by the sedimentation of particulate matters including soil materials. As a result,wetland's retention capacity can be lowered down(Renella 2021),reservoirs' bed can be raised up(Renella 2021), evaporation losses can be increased (de Araújo *et al.* 2006),and eutrophication processes can be accelerated(Owens *et al.* 2005).So, it is crucial to reclaim the wetlands to protect the water supply and biodiversity through excavating the bottom bed materials. Dredging is an operative method for excavating and re-excavating land to improve the wetland's water bearing ability (Yozzo *et al.* 2004; Kondolf *et al.* 2014).Globally, millions of tons of dredged sediment are produced by incessant dredging. For instance, around 200 m^3 of dredged material are thought to be produced annually in Europe (Wójcikowska-Kapusta *et al.* 2018; Mymrin *et al.* 2017; SedNet 2014).

Wetland's bottom sediment (soil) is an indispensable part of an ecosystem (Szara-Bąk *et al.* 2023) and possesses distinct hydrology and unique physical setting. Its physicochemical and biological characteristics are vital anthropopressure indicator (Baran *et al.* 2012; Jasiewicz *et al.* 2011). Sediments can improve terrestrial soil pH (Kiani *et al.* 2021; Baran *et al.* 2012; Wiśniowska-Kielian and Niemiec 2007a, b), soil aggregate (Tarnawski *et al.* 2015; Renella 2021), soil organic carbon (Tarnawski*et al.* 2015; Macia *et al.*2014), soil total N, extractable P (Tozzi *et al.* 2020), Exchangeable K, microbial biomass (Wobus *et al.*2003), sorption properties (Tarnawski *et al.* 2015; Canet *et al.* 2003) and crop productivity (Kazberuk *et al.* 2021; Canet *et al.*2003). Considering the larger issue of global food security and soil sustainability, wetlands' sediment availability as fertilizers can be a key component in upland agriculture.

Many researchers (kiani *et al.* 2021; Braga *et al.* 2017; Baran *et al.* 2016; Tarnawski *et al.* 2015; Capra *et al.*2015) underscored the recycled use of excavated sediment for terrestrial agriculture. This usage of sediment is recommended only when the toxic contaminant content is the below maximum permissible limit (Nygård and Purhonen 2019; Sapota *et al.* 2012; Finnish Water Directive 2011). Before utilization, their evaluations in terms of the nature and quality are prerequisites (Ferrans *et al.* 2019; Couvidat *et al.* 2018), because wetland sediment is influenced by numerous variables. These include (i) the nature and quality of stream water feeding wetland (ii) anthropogenic and agricultural activities (fertilizer, pesticide etc. applications) in the wetland and adjoining terrestrial areas (iii) the nature of adjacent landscape (hills or plain land) and soils (alluvial or colluvial) (iv) Runoff water quality and quantity reaching the water body, and (v) Openness of wetland, etc. Therefore, in the light of above discussion it can be said that inland wetlands as well as their sediments vary from one to another. Furthermore, the responsible factors can give a unique make up of sediment in certain wetlands in a region. In addition, in the areas like our study sites where flood water visits in the wet season, previously collected sediment could be used for pot culturing of vegetables to meet up the daily needs of affected people. In humid sub-tropics, runoff induced uni-directional loss-gain phenomenon of soil materials between laterally embedded terrestrial land and wetland can be transformed into reversible phenomenon (a sustainable approach) through reuse of the wetland’s bottom sediment in terrestrial upland. The evaluation of the diverse sediments and their utilization in different generic terrestrial upland might give encouraging and/or different results. Therefore, the present study has been designed to evaluate the selected wetlands' sediments regarding physicochemical attributes including heavy metals, and their potentiality to be used in stem amaranth cultivation with or without mixing with different generic farmers' field soils in terrestrial ecosystem.

MATERIALS AND METHODS

Two studies were performed to address the objectives of this research work.

Study 1: Assessment of physicochemical attributes and heavy metal contaminants in three unique wetlands’ sediment

*Study areas:*Three unique and genetically different wetlands (two *haos*anda*beel*)of Bangladesh were the study areas of this research work(Figure 1). One of the study sites is thewetland of hilly area I(locally known as Hakaluki haor) which is the largest wetland in Bangladesh, located in the adjacent to Assam border close to hills. The rapid degradation of the ecology of this land is causing devastating consequences on the community surrounding the land. Its home country Bangladesh has declared it as an “Ecologically Critical Area” in 1999 (Talukder and Murshed, 2021). Another site iswetland of hilly area II (locally known as Tanguar Haor) which isa unique wetland ecosystem located in Bangladesh, adjacent to Indian hills which bears natural importance and serves as the source oflivelihood for more than 40,000 people. The host country Bangladesh has also declared it as an “Ecologically Critical Area” in 1999 for its overexploitation (www.wikipidia.org.). In addition to foreign hills (India, Assam), the adjoining area in Bangladesh (for wetland of hilly areas I and II) is characterized by the presence of numerous small hills (locally called “tillas”). The third site iswetland of floodplain area (locally known as Chalan Beel) which is one of the largest and richest non-tidal wetlands of Bangladesh. It comprises a series of depression interconnected by various channels. This marshy land is being silted up rapidly (Alam and Hossain, 2021).

*Soil samples collection, processing and analysis:*Forty geo-referenced soil samples (sediment) with the assistance of a GPS device (0-20 cm, around 3 kg each) from each site were collected in a zig-zag random fashion maintaining a distance of around half a kilometer between sampling points (Figure 1). Composite soil samples were obtained by mixing collected samples for each site. Sub-sampling was done from each composite sample, and they were processed for further analysis (K, P, S, Ca, Mg, Zn, Fe, Mn, Cu, Cd, Pb and Ni) by using standard methodology (SI 1). Remaining soils were used as a media for pot culture.

*Non-specific biomass targeted soil/sediment pollution risk by heavy metals (Zc):*Total heavy metal pollution index (Zc) was counted by the following formula (Saet *et al.* 1990)

$$Zc = \sum Kki - (n - 1)\ldots\ldots\ldots\ldots \quad (1)$$

Where Kki was the ratio (from observed analytical value and reference value) of the i-th element; n was the number of elements as pollutants.

*Plant specific targeted soil/sediment pollution risk by heavy metals as nutrient element:*Total Heavy metal (nutrient) pollution index (Zc_n) was defined and found by the following formula:

$$Zc = \{\text{Metal (as nutrient) conc. in soil} - (\text{Critical nutrient concentration} \times 3)\}\ldots\ldots\ldots \quad (2)$$

Study 02: Assessment of sediments as media for pot culturing of a fast-growing crop stem amaranth in Eutric Gleysols and Dystic Cambisols

*Study site:*Two pot experiments were conducted at the experimental net house of the Department of Soil Science at Sylhet Agricultural University, Sylhet (Elevation: 22.56 meters, North latitude: $24^{o}54'39.16''$ and East longitude: 91°54′04.79″). Sylhet region experiences average rainfall of approximately 500 mm and average temperature of 25ºC during the month of August to November due to its humid subtropical monsoon environment.

*Pot cultured experiments:*Each pot (diameter 13 cm and height 16 cm)was filled with 3.3 kg of collected soil and/or sediment as stated in study 1. The experiment encompasses seven different treatments, namely:T_0: Farmer's field soil (FFS) [EutricGleysols for 1st pot experiment and DysticCambisols for 2nd pot experiment]; T_1: FFS + Wetland sediment of hilly area I (1:1); T_2: FFS + Wetland sediment of hilly area II (1:1); T_3: FFS + Wetland sediment of floodplain area (1:1); T_4: Wetland sediment of hilly area I; T_5: Wetland sediment of hilly area II; T_6: Wetland sediment of floodplain area. The initial statuses of EutricGleysols &DysticCambisols are presented in Table 1.

Completely Randomized Design (CRD) was followed with three replications maintaining the space 30 cm and 30 cm, respectively, between two pots and two rows for each experiment. All experimental pots for both experiments received the recommended dose of fertilizers (Urea 195.6 and 195.6 kg ha^{-1}, TSP 140 and 120 kg ha^{-1}, MoP 85.254 and 90.15 kg ha^{-1}, Gypsum 75.136 and 70.15 kg ha^{-1} for the first and second studies, respectively) based on soil test value which was calculated by the formula from Fertilizer Recommendation Guide (FRG, 2018). Based on the pot soil pH value, 1 g kg^{-1} soil (2 t ha^{-1}) of lime was applied as dolomite in accordance with the Fertilizer Recommendation Guide (FRG, 2018) and a literature review (Nazrul and Shaheb 2016).Vermicompost as organic amendments were applied at a rate of 1 g kg^{-1} soil (2 t ha^{-1}) and 0.5 g kg^{-1} soil (1 t ha^{-1})for the first and second experiment, respectively at 10 days after germination.

Seed sowing: Twenty seeds of stem amaranth were broadcasted at each of the experimental pot on 25th August 2022 (For 1st pot experiment) and on 1st September 2022 (For 2nd pot experiment).

*Data collection:*Plant heights, perpendicular canopy with canopy widest width were measured three times from all plants during the growth stage. Furthermore, plant growth index was calculated by using following formula(Liu *et al.* 2019):

$$\text{Plant growth index (PGI)} = \frac{\textit{Plant height}}{2} + \frac{\textit{Perpendicular canopy width + Canopy widest width}}{4} \ldots\ldots\ldots \quad (3)$$

At harvest, stem, leaf and root biomasses were recorded separately and they were dried in oven.

*Collection, preparation & analysis of plant samples:*While harvesting, plant samples were taken, air dried, oven dried, ground and kept in pot for analysis. The mineral nutrients in the processed plant samples under two studies were quantitatively determined in laboratory (SI 2).

*Nutrient uptake calculation:*Nutrient uptake by stem was calculated by using following formula:

$$\text{Nutrient uptake in stem}\ (\text{mg}/\text{kg}) = \frac{\textit{Nutrient concentration in stem (\%)} \times \textit{Yield (mg/pot) (dry basis)}}{100} \ldots\ldots\ldots \quad (4)$$

*Statistical analysis and graphical presentation:*Treatment effects were determined using analysis of variance (ANOVA), and treatment means were compared using the Duncan Multiple Range Test (DMRT) at a 5% level of significance in accordance with the basic principles outlined by Gomez and Gomez (1984).Obtained dataset were statistically analyzed in R console platform(v4.1.0; R Core Team 2021). Plant growth index (PGI) was graphically presented in line graph against different DAGs in spreadsheet.

RESULTS

Experiment 01: Assessment of various wetlands (marsh) sediments in respect to their physicochemical attributes and contents of contaminants of heavy metal

*Physicochemical attributes of initial wetlands' sediments used in the study:*Physical attributes of wetlands' sediments are shown in Table 1. The overall pH value indicates that soils were very strongly to strongly acidic. The highest soil pH (5.84) and EC (0.080 ds/m) were found in wetland sediment of hilly area II while lowest pH (4.45)was found in wetland sediment of hilly area I, and the lowest EC (0.067 ds/m) was in wetland sediment of floodplain area. The overall OC was observed as low to very low (0.84-1.52 %)in studied sediments. The highest PD (2.25 g/cc) was observed in wetland sediment of floodplain area followed by wetland sediment of hilly area I.

Total N, exchangeable K, soil extractable P, S, Ca, Mg, Zn, Fe, Mn and Cu are shown in Table 2. The highest amount of total N, soil extractable S, Fe, Mn and Cu figuring 0.09%, 69.81 mg/kg, 16.15 mg/kg, 7.30 mg/kg and 1.48 mg/kg, respectively were found in the sediment of hilly area I. Exchangeable K (0.18 meq/100g soil), soil extractable P (235.15 mg/kg), Ca (2.78 0.18 meq/100g soil) and Zn (3.08 mg/kg) were observed on the highest in the wetland sediment of hilly area II. On the other hand, soil extractable Mg (1.77 meq/100g soil) was observed on higher in the sediment of floodplain area. Among the observed heavy metals, only Cd, Pb and Ni were found higher than the maximum permissible addition for all sediments (Table 3).

The highest Cd (1.14 mg/kg) was found in the wetland sediment of hilly area II followed by wetland sediment of hilly area I. The highest Pb (164.71 mg/kg) was found from wetland sediment of floodplain area followed by wetland sediment of hilly area I. Concentration of other contaminants such as Cu, Zn, and Ni were found lower than the maximum permissible addition (Table 3). But the collective risk of all heavy metals was non-dangerous for all sediments (Tables 5 & 6).

Experiment 02: Evaluation of sediments as media for pot culturing of a fast-growing crop stem amaranth in EutricGleysols and DysticCambisols

Plant growth index (PGI) in EutricGleysols

At 10 days after germination (DAG), the highest PGI (9.77 cm) was observed from T_4 treatment receiving wetland sediment of hilly area I (Figure 2) while the lowest one (4.25 cm) was found from T_3 treatment. At 20 DAG, the highest PGI (29.03 cm) was observed in T_5 treatment and the lowest PGI was 18.10 cm from T_1 (EutricGleysols + wetland sediment of hilly area I) treatment. At harvesting, the highest PGI (75.06 cm) was found in T_5 treatment (wetland sediment of hilly area II), and the lowest one (34.01 cm) was found in T_1 treatment.

In case of combined use of different wetlands' sediment andEutric Gleysols as compared with T_0 treatment, the highest PGI (61.13 cm) was observed in T_2 treatment at harvest. On the other hand, different wetlands' sediment (when considered as sole utilization) compared with T_0 treatment, the highest PGI (75.06 cm) was observed in T_5 treatment at harvest.

Plant growth index (PGI) in DysticCambisols

In DysticCambisols, the highest PGI (13.96 cm) was observed at 10 DAG from T_5 treatment receiving wetland sediment of hilly area II (Figure 3). The lowest one (6.17 cm) was found from T_6 treatment (wetland sediment of floodplain area). At 20 DAG, the highest PGI (34.69 cm) were observed from T_5 treatment receiving wetland sediment of hilly area II. The lowest PGI was 18.16 cm found from T_2 treatment. At harvesting, the highest PGI

(65.91 cm) was observed in T_5 treatment and the lowest one (51.63 cm) was found in T_2 treatment. Almost all cases, treatment T_5 gave higher PGI for both studies. Although treatment T_4, T_5 and T_6 were the same for both pot studies, the higher PGI was observed in 2nd pot study, might be due to temporal variation of the growth. Combined use of sedimentsof Hakaluki haor and DysticCambisols exhibited highest PGI (58.57 cm) at the time of harvest. Conversely, as compared to the T_0 treatment, the highest PGI (65.91 cm) was observed in the T_5 treatment at harvest.

Fresh biomass production

Fresh biomass production in different plant parts of stem amaranth grown in both pot experiments varied significantly due to the application of different treatments (Table 5). In the 1st pot experiment, the highest fresh weights of stem, root and leaf were recorded as 148.52, 25.27 and 72.71 g pot^{-1}, respectively in the T_5 treated pot. And, the minimum weights of stem, root and leaf were 29.26, 5.32 and 14.63 g pot^{-1}, respectively in the pot with the treatment T_1. Consequently, the T_5 treatment yielded the highest fresh weight (total) of 246.49 g pot^{-1} and the pot with T_1 treatment gave the lowest fresh weight (total) of 49.21 g. Treatment T_5 was followed by treatment T_2 which was followed by treatments T_3 in yielding total fresh biomass. In the case of utilizing a combination of sediment from various wetlands' and EutricGleysols compared to the T_0 treatment, the highest total fresh biomass (179.55 g pot^{-1}) was recorded in T_2 treatment. On the other hand, as compared to the T_0 treatment, the highest total fresh biomass (246.49 g pot^{-1}) was observed in the T_5 treatment.

Similarly, in the 2nd pot experiment, the highest fresh weight of stem, root and leaf was recorded as 203.93, 22.61 and 100.19 g pot^{-1}, respectively in the T_5 treated pots. And, the lowest weights of stem and root were 59.85 and 5.32 g pot^{-1}, respectively in the pot with the treatment T_2 while the lowest weight of leaf was 23.50 g pot^{-1} in the pot with the treatment T_1. Eventually, the T_5 treatment gave total fresh weight (highest) of 330.73 g and the T_2 treatment yielded the total fresh weight (lowest) of 106.84 g. Treatment T_5 was followed by treatment T_6 which was followed by treatments T_3 in yielding total fresh biomass. In case of integrated use of field soil and sediment, T_3 showed the highest total fresh biomass (183.54 g pot^{-1}). But, the highest total fresh biomass (330.73 g pot^{-1}) was observed in the T_5 treatment (Tanguar haor) among all sole usage of sediments.

Dry biomass production

Dry biomass for different parts of stem amaranth varied significantly by the application of different treatments in both pot experiments as shown in Table 6. In case of 1st pot experiment (in EutricGleysols), the highest dry stem, root and leaf weight was found as 9.89, 3.08 and 6.06 g pot^{-1}, respectively in the pot receiving T_5 treatment. The lowest stem and root weights were recorded as 1.80 and 0.60 g pot^{-1}, respectively in the T_1

treated pot, while the lowest leaf weight was 3.47 g pot^{-1} found from T_0 treatment. As a consequence, the T_5 treated pot gave the highest total dry weight of 19.03 g pot^{-1} while the T_1 pot gave the lowest total dry weight of 6.42 g pot^{-1}.

In case of using a combination of sediments from various wetlands and EutricGleysols, the highest total dry biomass (15.96 g pot^{-1}) was recorded in the T_2 treatment. On the contrary, when we used sediment (sole) from different wetlands the highest total dry biomass (19.03 g pot^{-1}) was observed in the T_5 treatment.

In the 2nd pot experiment (in DysticCambisols), the highest dry stem, root and leaf weights were found as 10.17, 3.46 and 6.58 g pot^{-1}, respectively in the pot receiving T_5 treatment. The lowest stem and root weights were recorded as 2.72 and 0.60 g pot^{-1}, respectively in the T_2 treated pot, while the lowest leaf weight was 3.83 g pot^{-1} found from T_1 treatment. As a consequence, the T_5 treated pot gave the highest total dry weight of 20.22 g pot^{-1} while T_2 treated pot gave the lowest total dry weight of 7.18 g pot^{-1}.In case of using a combination of sediment from various wetlands andDystic Cambisols, the highest total dry biomass (14.67 g pot^{-1}) was recorded in the T_2 treatment. On the contrary, considering sole use of sediments from different wetlands, the highest total dry biomass (20.22 g pot^{1}) was observed in the T_5 treatment.

Nutrients uptake in stem

In case of first pot experiment, significant differences were observed for nutrient uptake in stem due to the different treatments which are shown in Fig. 4. Use of wetland sediment of hilly area II as a growing media (T_5) resulted the highest P, K, S, Ca, Mg, B, Zn, Fe and Mn uptakes figuring 2399.98, 11915.40, 3087.86, 5733.04, 1073.38, 114.50, 130.75, 801.96 and 156.63 mg kg^{-1} respectively. But highest Cu (9.89 mg kg^{-1}) uptake was recorded from combined use of EutricGleysols and wetland sediment of hilly area II (T_2).

When considering the mixed treatment in comparison to the control (T_0), the uptake of all mineral nutrients was found to be highest in the T_2 treatment compared to the other treatments. The lowest uptake of P, K, S, Ca, Mg, B, Zn, Fe, Mn and Cu were in pots with combined use of EutricGleysols and wetland sediment of hilly area I (T_1).

In case of second pot experiment, significant differences were observed for nutrient uptake in stem due to the different treatments which are shown in Fig. 4. The highest uptake of P, K, Ca and Mn figuring 3955.86, 12035.90, 3341.68 and 165.46mg kg^{-1}respectively, were observed in pots with the use of wetland sediment of hilly area II as a growing media (T_5). But the highest S, Mg, Zn, Fe and B uptakes figuring 2519.89, 1043.86, 81.71, 1753.15 and 368.36mg kg^{-1} respectively, were recorded in wetland sediment of floodplain area (T_6).

In case of integrated use of sediments and fields soils, the uptake of all mineral nutrients was found to be highest in the T_3 treatment compared to the other treatments. The lowest uptakes of P, S, Ca, Mg, B, Zn and Mn in pots with the combined use ofDysticCambisols and wetland sediment of hilly area II (T_1). On the other hand, the lowest uptakes of K, Fe and Cu were in pots containing DysticCambisols (T_0).

DISCUSSIONS

Physical attributes of different wetland sediments

The pH value of the studied sediments was observedas strongly to very strongly acidic might be due to the presence of acidic ions. Due to residence in submerged condition, it was supposed that sediments in wetland were in neutral or near neutral in reaction in *in-situ* condition. Similarly, soil OC was observed low to very low. In actual submerged condition the OC were expected to be higher. But, after soil sample collection, these soils got oxidized during drying of wet sediments and eventually OM content lowered down.

Soil (sediment) pollution risk by heavy metals

The heavy metal concentrations of the different sediments are shown in Table 3. For nonspecific biomass, overall collective risk of all heavy metals of the studied heavy metals in the study area could be regarded as not dangerous as per the literature (Zc) by Saet *et al.* (1990). It may be due to the concentrations of heavy metals in sediments were lower than the maximal permissible addition (MPA), (MPA as reported by Crommentuijn *et al.* 1997). On the contrary, in case of plant specific (stem amaranth) targeted soil (sediment) pollution risk by heavy metals used as plant nutrients (Cu and Zn) were observed on very high to excess in the studied area as per our proposed pollution risk index (Zc_n) (Table 4).Baran *et al.*(2019) also confirmed that the addition of sediment ina dose of 50% to a sandy soil increased the contents ofZn and Cu, which supports our finding.

Growth, yield and nutrient uptake of stem amaranth

The application of different treatments considerably changed the growth and yield parameter of stem amaranth. For both net house studies, in all cases, the T_5 treatment containing wetland sediment of hilly area IIperformed better than the remaining treatments in contributing increment of growth and yield parameters. This result might be due to the plant's ability to take up significantly greater amounts of P from the sediment than from sole soil, as wetland sediment of hilly area II contained more easily soluble P than sole farmers' soil (Table 2). The statement of Baran *et al.*(2019) supports this finding, who states that different doses of sediments to sandy soil significantly increased the contentof available P. In addition to P, the majority of easily soluble macro- and -micronutrients were considerably more abundant in the sediment than the others, which enhanced suitable conditions (fertility) for plant growth. These nutrients are likely originated from upper agricultural soils, which, through erosion, and deposition reached the bottom of the lake sediment (Kisic *et al.* 2002; Fonseca *et al.*2010; De Vincenzo *et al.* 2019). Canet *etal.* (2003) also reported an increase in lettuce yield due to the nutrient contents of the sediments and the possible improvement of the cation exchange capacity. Our finding is supported by recent studies reporting that the sediment mixture had comparable growth performance for holm oak seedlings (Ugolini *et al.* 2018), ornamental Red Robin photinia (Mattei *et al*. 2017), lettuce (Canet *et al.* 2003), and strawberry (Tozzi*et al.* 2020) compared to others. Compared to the 1st study, 2nd study showed the higher growth and yield in almost all cases. This was due to, as per our observation, the fact that seedlings under 1st pot experiment faced heat stress. And, 2nd pot experiment escaped the period for late sowing.

The uptake of nutrients such as P, K, S, Ca, Mg, B, Zn, Fe and Mn (for 1st pot experiment) and P, K, S and Ca (for 2nd pot experiment) in stem were found to be higher in the pot with treatment T_5 using wetland sediment of hilly area II. This could be due to the higher initial nutrients' concentration in this sediment. Our findings partially align with Islam *et al.* (2020) who observed that pond sediments revealed a higher quantity of nutritional contents in Indian spinach.

CONCLUSIONS

The collective risk of all heavy metals was non-dangerous for all studied sediments collected from wetland sediment of hilly area I, wetland sediment of hilly area II, and wetland sediment of a floodplain area.Wetland sediment of hilly area II as a vegetable crop growing media gave better growth and yield among the studied sediments. So, the use of wetland sediment as a growing medium can be beneficial to produce amaranth as vegetable especially for flash flood prone wetland areas. Further field trial is neededto extrapolate the findings in a larger scale.

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STATEMENTS AND DECLARATIONS

Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Table 1Physical attributes of three wetlands'sediments and farmer's field soils.

Sediment / Soil	pH	OC (%)	EC (ds/m)	PD (g/cc)	Texture	Consistency
Wetland sediment of hilly area I	4.45	1.52	0.067	2.16	Sandy clay loam	Firm
Wetland sediment of hilly area II	5.84	0.84	0.080	2.23	Sandy clay loam	Very firm
Wetland sediment of floodplain area	5.34	1.04	0.063	2.25	Sandy loam	Firm
Eutric Gleysols	6	1.48	0.082	2.39	Clay loam	Very firm
Dystic Cambisols	6.1	1.00	0.084	2.23	Sandy loam	Firm

OC = Organic carbon, EC = Electrical conductivity, PD = Particle density

Table 2Chemical attributes of initial sedimentsand farmer's field soils.

Elements	Wetlands' Sediments			Farmers' Field Soils	
	Hilly area I	Hilly area II	Floodplain area	Eutric Gleysols	Dystic Cambisols
N^T (%)	0.09 (Very low)	0.07 (Very low)	0.06 (Very low)	0.095 (Low)	0.07 (Very low)
K^{Exc} (meq/100g soil)	0.13 (Low)	0.18 (Medium)	0.05 (Very low)	0.08 (Very low)	0.09 (L0w)
P^E (mg/kg)	40.62 (Very high)	235.15 (Very high)	64.13 (Very high)	11.1 (Medium)	5.00 (Medium)
S^E (mg/kg)	69.81 (Very high)	57.74 (Very high)	29.17 (Very high)	10.5 (Low)	9.80 (Low)
Ca^E (meq/100g soil)	1.59 (Low)	2.78 (Low)	2.15 (Low)	-	-
Mg^E (meq/100g soil)	1.50 (Optimum)	1.52 (Optimum)	1.77 (High)	-	-
Zn^E (mg/kg)	1.85 (High)	3.08 (Very high)	2.63 (Very high)	-	-

Fe^E (mg/kg)	16.15 (Very high)	11.50 (High)	9.83 (High)	-	-
Mn^E (mg/kg)	7.30 (Very high)	2.67 (Optimum)	4.44 (Very high)	-	-
Cu^E (mg/kg)	1.48 (Very high)	0.85 (Very high)	1.25 (Very high)	-	-

T= Total, Exc= Exchangeable, E= Extractable; Interpretation (within the parenthesis) for the soil test values was done based on FRG (2018).

Table 3 Nonspecific biomass targeted soil (sediment) pollution risk by heavy metals.

Elements	**Observed analytical value (mg/kg)**			**MPA as Reference value (RV) (mg/kg)**	**Ratio (SH-I /RV)**	**Ratio (SH-II/RV)**	**Ratio (SF/RV)**	**Collective Risk of All heavy metals and comments (As adapted from Saet *et al.* 1990) (Zc)**		
	Sediment of Hilly area I (SH-I)	**Sediment of Hilly area II (SH-II)**	**Sediment of Floodplain area (SF)**					**SH-I**	**SH-II**	**SF**
Cu (mg/kg)	1.48	0.85	1.25	3.5	0.42	0.24	0.36	16.93: No Dangerous	15.59: No Dangerous	13.71: No Dangerous
Zn (mg/kg)	1.85	3.08	2.63	16	0.12	0.19	0.16			
Cd (mg/kg)	1.06	1.14	1.05	0.76	1.39	1.5	1.38			
Pd (mg/kg)	102.88	64.71	164.71	55	1.87	1.18	2.99			
Ni (mg/kg)	44.54	42.86	33.33	2.6	17.13	16.48	12.82			

MPA= Maximal permissible addition

Table 4Plant specific (stem amaranth) targeted soil (sediment) pollution risk by heavy metals used as plant nutrients

Elements	Current Status			Risk of Heavy Metals as Nutrient Element (Zc_n)			Zc_n values with annotation			
	SH-I	SH-II	SF							
	(mg/kg)			SH-I	SH-II	SF				
Cu (mg/kg)	1.48	0.85	1.25	0.88	0.25	0.65	Less than zero (<0): Lower than plant requirement	Equal or near to zero (0): Optimum	Greater than zero (>0): High to very high	Great greater than zero (>>0): Excess to toxic
Zn (mg/kg)	1.85	3.08	2.63	0.05	1.58	1.13				

SH-1= Sediment of Hilly area I, SH-II= Sediment of Hilly area II, SF= Sediment of Floodplain area

Table 5 Fresh biomass of stem amaranth produced in first and second pot experiments under different treatments at harvest

Treatments	Fresh biomass (g pot^{-1})							
	1st Pot Experiment (EutricGleysols)				2nd Pot Experiment (Dystic Cambisols)			
	Stem weight	Root weight	Leaf weight	Total Fresh Weight	Stem weight	Root weight	Leaf weight	Total Fresh Weight
T_0	34.58 ± 1.15 ef	6.65 ± 0.58 ef	19.06 ± 1.20 e	60.29 ± 0.66 e	67.39 ± 1.66 e	9.31 ± 0.58 e	31.92 ± 1.73 f	108.62 ± 3.71 e
T_1	29.26 ± 2.51 f	5.32 ± 0.58 f	14.63 ± 1.15 e	49.21 ± 3.60 e	85.56 ± 2.60 d	11.97 ± 0.58 de	23.50 ± 1.45 g	121.03 ± 3.51 e
T_2	106.4 ± 4.16 b	17.73 ± 0.88 b	55.42 ± 0.88 b	179.55 ± 3.79 b	59.85 ± 1.53 e	5.32 ± 0.58 f	41.67 ± 1.45 e	106.84 ± 2.73 e
T_3	70.05 ± 2.02 c	13.74 ± 0.88 c	42.65 ± 2.08 c	126.35 ± 3.79 c	105.51 ± 2.96 c	16.85 ± 0.66 c	61.18 ± 3.21 c	183.54 ± 6.08 c
T_4	53.64 ± 2.33 d	11.08 ± 0.33 cd	32.36 ± 1.45 d	97.09 ± 2.88 d	91.77 ± 2.30 cd	15.07 ± 0.88 cd	50.54 ± 1.15 d	157.38 ± 2.33 d
T_5	148.52 ± 4.33 a	25.27 ± 1.53 a	72.71 ± 2.19 a	246.49 ± 7.68 a	203.93 ± 7.51 a	22.61 ± 1.00 a	100.19 ± 2.30 a	330.73 ± 9.26 a
T_6	43.00 ± 2.02 de	9.75 ± 0.33 de	29.70 ± 1.20 d	82.46 ± 3.21 d	131.23 ± 4.63 b	26.6 ± 1.53 b	70.49 ± 2.19 b	224.33 ± 4.06 b
CV (%)	9.51	14.87	9.21	7.93	8.33	13.33	8.64	6.60
LS	***	***	***	***	***	***	***	***

Values are mean ± SEM (Standard Errors of Mean), Means followed by different letter in a column are significantly different at 0.1% level by LSD, LS = Level of significance, CV = Co-efficient of variation, T_0: Farmer's field soil (FFS) (Eutric Glaysols for 1st pot experiment and Dystic Cambisols for 2nd pot experiment); T_1: FFS + Wetland sediment of hilly area I (1:1); T_2: FFS + Wetland sediment of hilly area II (1:1); T_3: FFS + Wetland sediment of floodplain area (1:1); T_4: Wetland sediment of hilly area I; T_5: Wetland sediment of hilly area II; T_6: Wetland sediment of floodplain area.

Table 6 Dry biomass of stem amaranth produced in first and second pot experiments under different treatments

Treatments	Dry biomass (g pot^{-1})							
	1stPotExperiment (EutricGleysols)				2nd PotExperiment (Dystic Cambisols)			
	Stem weight	Root weight	Leaf weight	Total Dry Weight	Stem weight	Root weight	Leaf weight	Total Dry Weight
T_0	3.43 ± 0.08 d	0.83 ± 0.01 ef	3.47 ± 0.38 d	7.74 ± 0.44 f	4.03 ± 0.11 f	0.79 ± 0.03 e	4.02 ± 0.08 c	8.80 ± 0.06 f
T_1	1.80 ± 0.14 e	0.60 ± 0.02 f	4.02 ± 0.19 cd	6.42 ± 0.04 f	5.09 ± 0.10 e	1.19 ± 0.04 d	3.83 ± 0.16 c	10.11 ± 0.26 e
T_2	8.41 ± 0.17 b	2.09 ± 0.02 b	5.45 ± 0.16 ab	15.96 ± 0.36 b	2.72 ± 0.05 g	0.60 ± 0.03 e	3.87 ± 0.09 c	7.18 ± 0.16 g
T_3	7.55 ± 0.28 b	1.37 ± 0.06 c	5.12 ± 0.22 abc	14.05 ± 0.26 c	7.29 ± 0.28 c	1.92 ± 0.10 c	5.26 ± 0.26 b	14.67 ± 0.37 c
T_4	6.38 ± 0.15 c	1.14 ± 0.02 cd	4.73 ± 0.52 bc	12.24 ± 0.39 d	6.50 ± 0.06 d	1.37 ± 0.03 d	5.19 ± 0.29 b	13.07 ± 0.35 d
T_5	9.89 ± 0.19 a	3.08 ± 0.15 a	6.06 ± 0.03 a	19.03 ± 0.06 a	10.17 ± 0.19 a	3.46 ± 0.07 a	6.58 ± 0.12 a	20.22 ± 0.11 a
T_6	3.93 ± 0.36 d	0.93 ± 0.01 de	4.25 ± 0.12 cd	9.11 ± 0.48 e	8.74 ± 0.05 b	2.48 ± 0.06 b	5.95 ± 0.14 ab	17.18 ± 0.27 b
CV (%)	8.41	10.20	13.51	6.38	5.24	8.49	8.50	4.45
LS	***	***	**	***	***	***	***	***

Values are mean ± SEM (Standard Errors of Mean), Means followed by different letter in a column are significantly different at 0.1% level by LSD, LS = Level of significance, CV = Co-efficient of variation,T_0: Farmer’s field soil (FFS) (Eutric Glaysols for 1st pot experiment and Dystic Cambisols 2nd pot experiment); T_1: FFS + Wetland sediment of hilly area I (1:1); T_2: FFS + Wetland sediment of hilly area II (1:1); T_3: FFS + Wetland sediment of floodplain area (1:1); T_4: Wetland sediment of hilly area I; T_5: Wetland sediment of hilly area II; T_6: Wetland sediment of floodplain area.

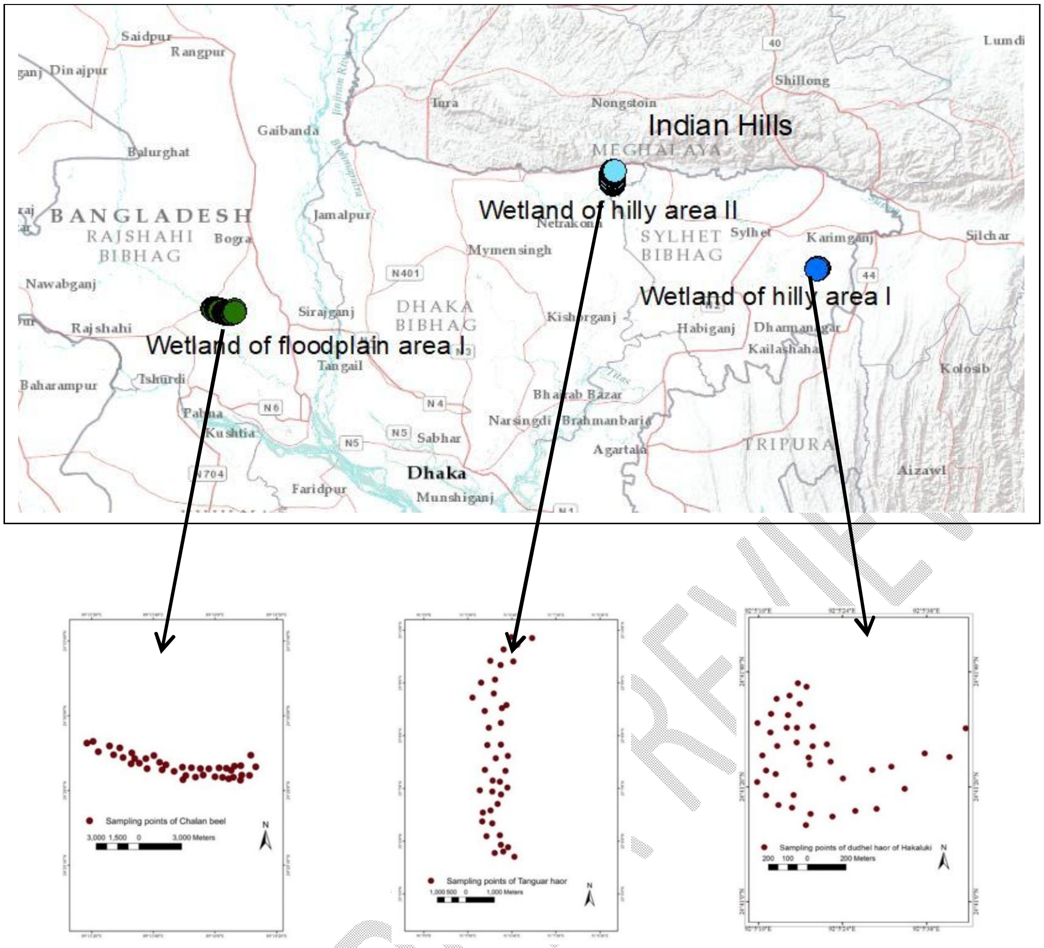


Fig. 1 Study sites and location of individual sediment samples (n=40 for each wetland) of the wetlands

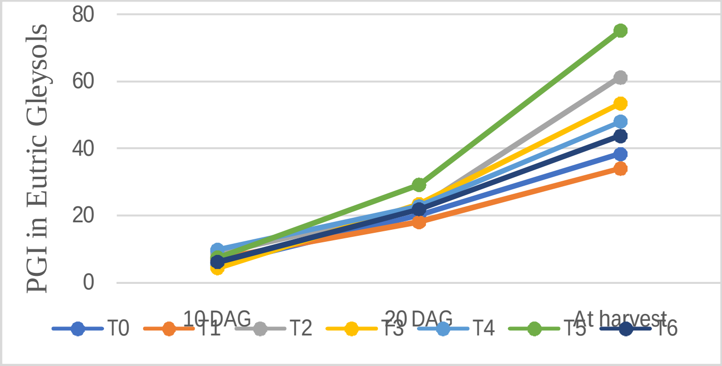


Fig. 2 Plant growth index (PGI) in Eutric Gleysols at different days after germination (DAG)

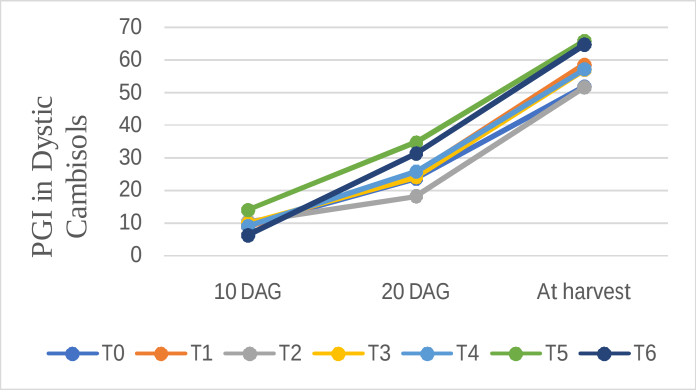
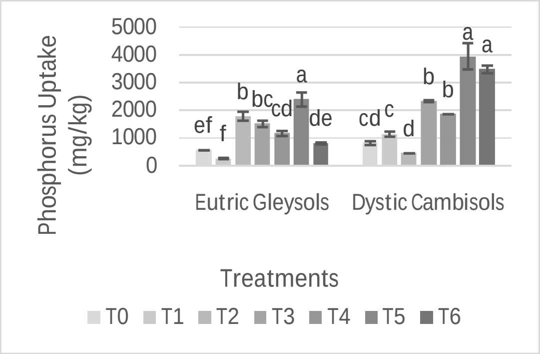
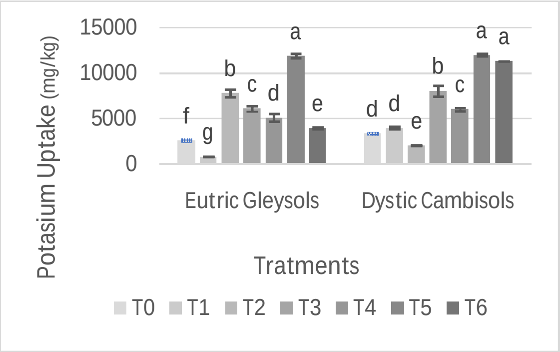


Fig. 3 Plant growth index (PGI) in Dystic Cambisols at different days after germination (DAG)





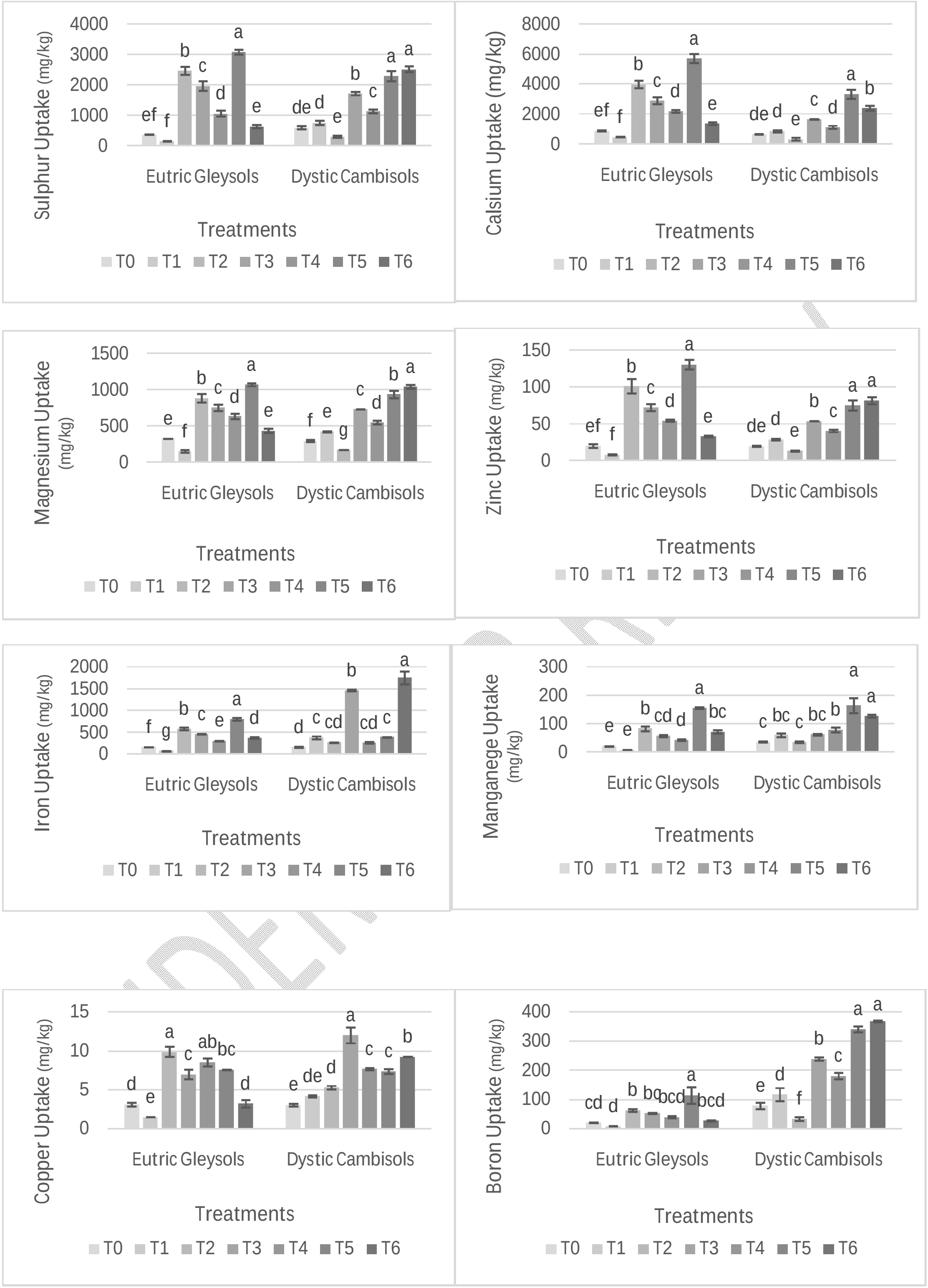


Fig. 4 Nutrients Uptake by Stem Amaranth