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ORIGINAL PAPER

Implementing Vetiver grass-based riverbank protection programmes in rural West Bengal, India

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Abstract
The largely impoverished rural communities of India are unable to bear the costs involved in creating and maintaining substantial structural measures for riverbank protection. The monsoonal nature of the country's streams and an agrarian economy based on intensive cultivation further heighten the risk posed by annual peak flows and shifting stream courses. Mitigating this requires urgent, sustainable and cost-effective means of conserving valuable farmlands and stabilising channel boundaries. Towards this, riverbank erosion mitigation using Vetiver grass has been a recent development in the country and has been experimented with in a few areas. In this article, we examine how such riparian buffers are created through riverbank modification, planted and nurtured and the effectiveness of the grass in mitigating erosion, taking a small case study from rural West Bengal as an example. We especially focus on the government policies and frameworks and local stakeholder involvements that facilitate such an undertaking, with particular emphasis on the organisational workflow and the ground-level perception of such endeavours, as these are crucial to the success and effectiveness of such schemes. The marked successes achieved through the use of the Vetiver grass in abating erosion and the hindrances encountered in implementing such mitigation projects are outlined, along with the importance of such community-based approaches to river management and monitoring. This case study can be a microcosm for similar such endeavours, particularly in the rural global south.

Keywords Ecogeomorphology · Riverbank erosion · Vegetation effects · Flood mitigation · Bioengineering · Riparian buffers

1 Introduction

Riverbank erosion and the subsequent sediment loss (Piegay et al. 2005; Florsheim et al. 2008) is regarded as a leading cause of water quality degradation and stream health impairment (Langendoen et al. 2012). It is further accelerated by riparian vegetation clearance (Abernethy and Rutherfurd 1998), channelisation, inappropriate dam construction and deliberate sand and gravel extraction (Kondolf 1997) that enhance channel instability

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and result in the loss of valuable adjacent riparian tracts, which are usually farmlands. Its effects are even more severe in already impoverished rural communities in developing nations, often forcing the dependant agrarian population into poverty (e.g. as seen along the Ganga, Brahmaputra and other rivers of eastern India—Das et al. 2014).

Erosion control projects, in general and in India, in particular, have largely focussed on utilising hard engineering structures relative to their softer counterparts (Allen and Leech 1997). These mostly comprise of ripraps, rock revetments, groynes, concrete walls and embankments, which are often short-term measures. These usually fail to effectively restore the local riparian ecology and instead end up degrading the existing stream condition [e.g. riprap slopes impede fish growth by altering habitat zones (Polster Environmental Services Limited 2003)]. They can also accelerate toe scouring through existent cracks and voids, thereby facilitating the loss of bank toe material and making it susceptible to undermining and slumping due to the hydrostatic pressure built up from behind (Lagasse et al. 2006). In sand bed channels, riprap aggravates erosion in the immediate downstream reaches (Scheireck 2001), while concrete flexmats restrict infiltration and impair vegetation growth (Torre 2001). Hard engineering techniques are also complex geotechnical systems, requiring considerable scientific expertise and skill to install and entail long-term maintenance costs, which can increase further if they are not properly installed (Bentrup and Hoag 1998).

Contrarily, bioengineering focuses on integrating the physical laws of hard engineering with the biological components of living plants (Stiles 1991) for restoring the geomorphic and ecological functionalities of unstable streams, through reinforcing and increasing the soil's resistance to erosive forces (Wells 2002) by using defensive vegetative walls along riverbanks for overall surface protection (Donat 1995). Such vegetated riparian zones influence the stream's hydrological functioning and its banks' geotechnical properties (Abernethy and Rutherfurd 2000; Maffra et al. 2017; Mulyono et al. 2018), thereby providing greater channel stability and allowing conservation of floodplain tracts. While such methods date back to as early as the first century B.C., when European rivers were often treated with living materials to mitigate erosion problems (Evette et al. 2009), they have regained prominence relatively recently as part of river restoration measures (Mondal and Patel 2018), after their impacts on channel dynamics have been better understood and many design models have been subsequently framed (Allen and Leech 1997). They can also enhance habitats for fish and micro-organisms by improving soil moisture conditions, while reducing the construction and maintenance costs of implanted structures and abet water quality improvement through phytoremediation (Caulk et al. 2000; Girija et al. 2016). Short-tem, expensive measures of hard engineering are thus being increasingly abandoned for their softer counterparts (Caulk et al. 2000), to deal with issues of erosion and bank instability, with these being the only viable alternative for developing nations like India (Ghosh and Bhattacharya 2018), where combating the problems of monsoonal flooding and consequent bank erosion is an annual necessity, in resource and capital scarce rural localities.

2 Using live vegetation for riverbank protection

Brush layering and mattresses, tree and log revetments and vegetated geogrids, live stakes and fascines, live crib walls and joint planting are the various bioengineering designs that are usually installed depending on the type and degree of erosion, site-specific conditions and on the implementation objectives (Li and Eddleman 2002; Eubanks and Meadows 2002; Veticon Consulting 2017). Biotechnical stabilisation measures can also be formulated by integrating vegetation with hard armouring for sites unable to attain self-stabilisation (Johnson 2006). For all of these, the selection of an appropriate plant species, which is both resource saving and aesthetically pleasing, is paramount, and in this respect, grasses possess unique abilities in combating soil erosion, being excellent compacting agents that bind detachable erosive soil and thereby consolidate bank slopes, owing to their tensile strength (Baets et al. 2008), along with conserving nutrients in bare soils (Babalola et al. 2003). Self-reproducing grass species, having high survival rates and resilient to adverse climatic conditions, are thus ideal (Liu et al. 2014; Lateh et al. 2014). While the low canopy and dense surface cover of Stylo (*Stylosanthes guianessis*) and Molasses (*Melinis* minutiflora) grasses shelter against rain splash erosion, Broom (*Thysanolaena maxima*) and Napier (*Pennisetum purpureum*) grasses reinforce the soil by increasing its shear strength (Kafle and Balla 2008). Another important criterion is the plant's anchorage capacity and root reinforcement power as the critical threshold values for these parameters indicate how it may resist the critical shear stress of flowing water (Fischenich 2001). Therefore, studies on the quantification of root length, density and surface area of these grasses and their effect on the scouring pattern have been undertaken to ascertain the effectiveness of local plant species in controlling bank erosion (Shit and Maiti 2012).

As regards the above, Vetiver grass has been widely acknowledged as one of the most promising erosion control methods. Native to the tropical belt and known by its traditional name of '*Khas Khas*' in northern India, the species, *Vetiveria zizanioides* (reclassified as *Chrysopogon zizanioides*), is mentioned in early Sanskrit writings and in Hindu mythology, not only for its roots with respect to erosion control and soil conservation but also for its multiple other uses (Maffei 2002). It was first cultivated in southern India for the aromatic oil extracted from its roots, with the practice subsequently spreading worldwide (Maffei 2002). This south Indian variety of the Vetiver is of 'domesticated' type, probably being a human-made variety from the wild grass. It is non-flowering and non-seeding (NRC 1993) and is especially suitable for erosion control. This densely tufted, tall (grass heights can vary between 1.5 and 3 m where growing conditions are favourable), perennial grass having a gregarious habit (Duke and duCellier 1993) can adapt to climatic extremes and withstand periods of prolonged drought and excess precipitation (Truong 1999a). It can grow in all soil types, being tolerant of high salinity, sodicity and acid sulphates (Truong and Baker 1996), and can adjust to a wide range of soil pH values (Truong and Baker 1996; Zeitz 2015). Being a hydrophyte, it grows best in areas of high rainfall and in almost all topographic forms, from high mountains to low plains and along river valleys (Maffei 2002), especially in well-drained sandy soils (Greenfield 1989). It propagates itself though small offsets instead of through underground stolons (USDA NRCS 2009) and is thus non-invasive and sterile and does not compete with neighbouring species, rather provides the microclimate that can induce the growth of other native grasses (Bertea and Camusso 2002).

Until the 1950s, before its application as a soil conservation tool, Vetiver was only used as thatching material for roofs and walls. It was first used to prevent soil erosion from intensively cultivated sugarcane fields in Fiji (NRC 1993), with similar scattered examples from Malaysia and the Caribbean (Ghosh and Bhattacharya 2018). Its success led the World Bank in the 1980s to further its use for similar purposes in the drought- and erosion-prone areas of central India (NRC 1993), with Vetiver systems being denoted as the 'hedge against erosion' (Okon and Babalola 2004). Since the plant's crown occurs just below the soil surface, it can resist trampling by cattle once fully grown, due to its tough mature foliage, whose thickness further helps to arrest overland flow and retard soil loss, and it has been documented from observations in Fiji and India to not only conserve soil loss from fields but to also raise the moisture content of soils and groundwater levels, thereby facilitating the cultivation of other crops (NRC 1993). However, at the administrative level, only very recently have attempts been made to use this grass for riverbank protection in India and we examine such instances from the south-western part of the eastern Indian state of West Bengal. The adoption of this technology by the local government bodies herein represents a paradigm shift in the manner in which such alternative (to hard engineering) bank stabilisation measures are now being devised and how their implementation incurs sustained inter-departmental and institutional interactions and ground-level village interfacing. This provides a glimpse into how a government-aided, community-managed vegetation-based riverbank protection scheme may function successfully, often in remote impoverished rural sites. The pros and cons elicited from examining such a framework can facilitate in designing suitable guidelines for other similar localities.

3 Objectives

This paper aims to:

- Outline the effectiveness of Vetiver grass in mitigating riverbank erosion,
- Discuss how a vegetation-based riverbank stabilisation scheme is designed and implemented in rural West Bengal, focussing on the institutional mechanisms that enable it, the actual physical modifications undertaken along the stream and the perceptions of the local inhabitants regarding such ventures, and
- Compare the cost-effectiveness of such bioengineering mitigation schemes versus traditional hard engineering methods.

4 Methods

Information regarding Vetiver grass effectiveness for erosion control was gleaned from published literature, available reports and newspaper articles. Documents prepared by local government agencies on such projects implemented in the study area were used to extract the aspects related to the implementation framework, costs involved and the institutional interactions. Local perceptions were gauged through a questionnaire survey undertaken among villagers at sites where the Vetiver had been planted to mitigate erosion. The questions centred on the perceived effectiveness of the grass in protecting the stretch of the riverbank, the involvement of the villagers in choosing the sites to be protected and on any other additional benefits accrued from planting the grass. A total station survey was conducted at Gholsai village (one of the sites chosen to plant the Vetiver grass) in January, 2019 (i.e. just during the planting and initial growth of the grass in the Indian winter/pre-monsoon months), to map the riverbank modifications undertaken for planting the grass. A repeat topographic profile survey was done at the same site in January, 2020, to ascertain the condition of the riverbank at the grass-protected location versus the adjacent unprotected stretches, after a full monsoon and post-monsoon season had elapsed, during which flows are at their highest.

5 Study area

This paper focuses on the application of Vetiver grass technology as a bioengineering tool for mitigating bank erosion along the River Ketia, an anabranching channel of the River Silabati, which drains the lateritic terrain of Paschim Medinipur district in the south-western part of West Bengal (Fig. 1). These channels are typical lowland channels (Rosgen Class C and E types, with broad floodplains, slightly entrenched channels, low to high width–depth ratio and moderate to high sinuosity—Rosgen 1994). Channel widths of the Silabati River range between 150 to 90 m in the examined stretches, and those of its distributaries/anabranches range between 50 to 80 m. Mean flow velocities range between 0.35 m/s during the lean season to up to 2.3 m/s during higher discharges (obtained via field surveys). During the rainy season, the Silabati River carries a substantial flood discharge to its lower stretches, with water levels regularly rising above its demarcated danger level of 8.99 m for the studied stretches, and the Ketia also accommodates part of the main monsoonal flow. The Ketia, in its lower reaches, further branches into the Katan, a secondary channel that joins the Silabati River downstream from where the Ketia flows back into the main channel. These streams cause annual floods and bank slumping in their lower reaches in Ghatal Block. A network of embankments of the *Zamindari era* (period of landed gentry in West Bengal who ruled during the Mughal and British empires in India) line the streams and their constant repair before each flood season has proved not only to be an expensive affair but has also resulted in progressive disruption of the crucial lateral continuity between the streams and their floodplains. Bank erosion and embankment breaches have continued unabated, with sand deposits left in the aftermath of floods, frequently rendering fields infertile. With traditional measures proving ineffective, Vetiver-based riverbank

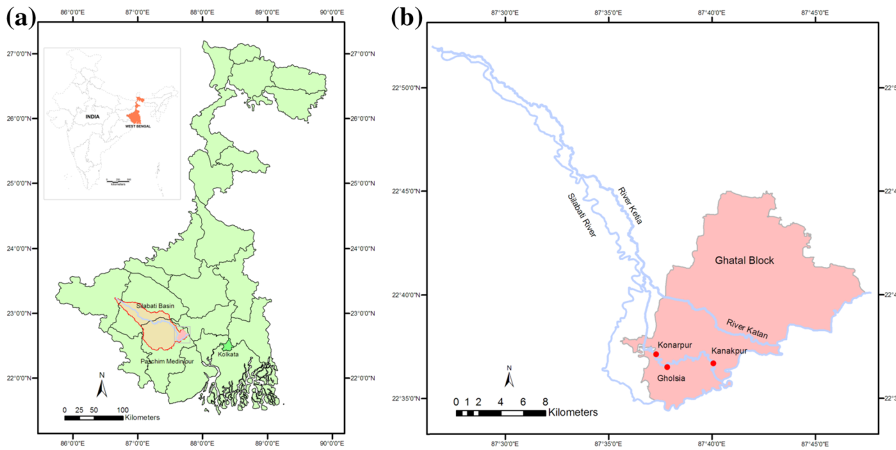

Fig. 1 Location map of the study area, showing **a** the Silabati River Basin in West Bengal, and **b** the sites along the Ketia River where Vetiver has been planted for riverbank protection

protection measures have been tried out at select spots to gauge their effectiveness in mitigating such hazards.

6 Vetiver grass utility in riverbank protection

Growing in dense hedges, Vetiver grass provides a two-way support to eroding slopes—the deep interlocking fibrous root system penetrates up to depths of 3 m providing good anchorage (Demirel and Demirel 2005), thus binding the soil and preventing its movement by increasing the soil shear strength and aiding slope stabilisation (Islam et al. 2017), while the hedges above ground trap sediments and reduce the flow velocity of the excess run-off occurring from rainstorms (Truong et al. 2008; Yinglun 2018). Even when planted closely at a spacing of 10 cm, its root network grows straight down without interfering with the growth of adjacent crops (Bertea and Camusso 2002), and demonstrations have shown that root lengths can reach depths of 1 m in 2 months and more than 2 m in just 3 months, even in unfavourable (hotter or colder) climates (NRC 1993). Studies show that a row spacing of 30 cm between plants is sufficient for short-term stabilisation of riverbanks if results have to be achieved swiftly (requiring a greater number of plants and thereby expense), whereas a spacing of 75 cm (if lesser numbers of saplings are available) shall also enable solutions in the long term, once the grass matures fully in due course (Ghosh et al. 2018). The Vetiver grass' total root length has been demonstrated to be directly correlated with the root shear stress and a full-grown plant increases the factor of safety (FoS) by up to 2.6 times on failed embankment slopes (Truong et al. 2008; Islam and Badhon 2016). With an average root tensile strength of 75 MPa (Hengchaovanich and Nilaweera 1996; Ghosh and Bhattacharya 2018), experimental research on failed embankments has revealed that the in situ shear strength of a Vetiver covered soil matrix could increase by up to 1.4 times that of bare soil and thereby greatly augment the FoS, which would consequently reduce the erosion amount by almost 70% (Nasrin 2013). Above ground, it can grow up to a height of 1.2 m but is usually trimmed once it is 15 cm high to spur faster growth and greater generation of tillers (Maffei 2002), while being a 'heavy bottom' grass, it is resistant to toppling. The hydraulic characteristics of Vetiver hedges have been shown to effectively retard the flood velocity, being able to resist flow velocities up to 5 m/s, resulting in little erosion along the bare slopes of a channel (Truong 2000; Truong et al. 2008). When combined with other living materials like bamboo canes and jute geogrids (both of which are indigenous to the study area), they effectively reduce the stream velocity, thereby trapping excess sediment (Noorasyikin and Zainab 2016; Tardio et al. 2017) and create slow-moving water pockets along the bank which precipitates part of the suspended load, gradually forming a berm-like feature along the bank toe that provides support to a toppling bank. Although it needs little or no maintenance, gap filling during the early years, regular pruning and annual cutting of the upper hedges bring about best results in erosion control (Grimshaw 1993), and standards have also been framed denoting the best possible times for sowing and harvesting the grass (Islam and Badhon 2017).

7 Vetiver buffers for riverbank protection in the Indian subcontinent

Ironically, though Vetiver use for soil loss control has been part of the traditional and indigenous knowledge base of India for centuries [as mentioned in the old Sanskrit texts, and were tried and adopted from here before its dissemination worldwide, particularly in the 1980s at the behest of the World Bank (Greenfield 1989; Ghosh and Bhattacharya 2018)], instances of Vetiver use for riverbank protection are rare and very recent from the Indian subcontinent, mainly due to administrative ignorance of its utility for this purpose and the lack of professional endorsement of the same from engineers (NRC 1993; Ghosh and Bhattacharya 2018). This has occurred due to the non-establishment of independent Vetiver trials and demonstrations by the administrative bodies themselves, in the aftermath of the trials and pilot projects done by the World Bank in India, as was mandated by their report (NRC 1993). Thus the present steady advent of this technology for combating riverbank erosion and slope stabilisation marks a significant shift in governance perceptions and policies. While other bioengineering methods, like the use of jute geotextiles, have been employed and investigated previously (e.g. Ghosh et al. 2016), the use of live vegetation for stream bank protection and their prior separate nurturing for this specific purpose is very new, with only a handful of case studies from the eastern and southern parts of the country (as per the International Vetiver Grass Tracking (iVGT App) database). This indigenous grass has been planted along a 900-m embankment stretch of the River Mundeshwari in Khanakul-I Block of Hooghly district in West Bengal under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), with results suggesting that the plant is an excellent stabilising agent, whose roots can effectively bind the loose soil, while its tufted hedgy bush sufficiently reduces the flood discharge velocity (PTI 2012). Regular pruning has enabled a more luxuriant growth, with the trimmed matter used as fodder for livestock. Its usefulness has been further proven when planted along the erosive banks of the River Bhagirathi at Bethuadahari in Nadia district of West Bengal, where it has significantly reduced erosion and stabilised the banks, with proper plant spacing important for optimum results and the Vetiver implants therein have also enhanced the soil fertility for other crops (Ghosh et al. 2018). The grass has also been used at multiple sites along the Teesta and Ichhamati Rivers (which are often in spate) in northern and southern West Bengal, respectively, for riverbank stabilisation (as per the iVGT App database). Planting of Vetiver along vulnerable reaches of the Devi River in Orissa at Bauriakan village, under threat from sand mining and liquefaction of the embankment, has been envisaged as an abatement measure against recurring floods (by increasing the roughness coefficient of the banks and thereby causing a drop in the flow velocity and a subsequent dampening of the flood peak) and bank slumping (Mishra and Subhalaxmi 2018). Vetiver has also been employed effectively for riverbank protection and hillside slope stabilisation in Assam, particularly in the Brahmaputra valley and along the Guwahati–Shillong Highway (Ghosh and Bhattacharya 2018). Its use for checking soil loss via run-off from agricultural fields has a slightly longer history, with recorded instances from the states of Uttar Pradesh, Maharashtra, Tamil Nadu and Karnataka (Greenfield 1990), while the multipurpose benefits of Vetiver planting was demonstrated from poverty-stricken villages in Karnataka, where infertile lands have been reclaimed through organic farming measures using this grass (Patil 1991). It has been used just as effectively across the international border in Bangladesh, along the Padma River, for slope stabilisation and bank erosion mitigation by high waves and tidal surges, along with the removal of heavy metals dumped into the channel via industrial effluents (Islam 2016), due to its inherent phytoremediative character (Danh et al. 2009; Sulee 2016; Sulee et al. 2017), which make it capable of reducing herbicide concentration, enhancing water quality parameters and even aiding in carbon sequestration (Chomchalow 2003a; Oshunsanya and Aliku 2017).

8 Facilitating Vetiver plantations along riverbanks-institutional processes

The Vetiver Grass Technology (VGT) (Grimshaw 2006a, b) has been implemented at a number of sites in the study area, specifically for riverbank protection. It was first tried out in the Monoharpur-I Gram Panchayat under Ghatal Block and its visible success (although no scientific measurements or reports were documented) led to the dissemination of information about the technique to other Gram Panchayats within the Block. Subsequent sites where the VGT has been implemented along the Ketia River are in the mouzas of Kuthi Konarpur, Kismat Kotulpur and Kanakpur in Dewanchak-I Gram Panchayat and in Gholsai in Dewanchak-II Gram Panchayat.

Sites that are most prone to erosion and have been affected by continuous toe scouring and slumping, are selected as the target sites for the VGT schemes by the concerned Gram

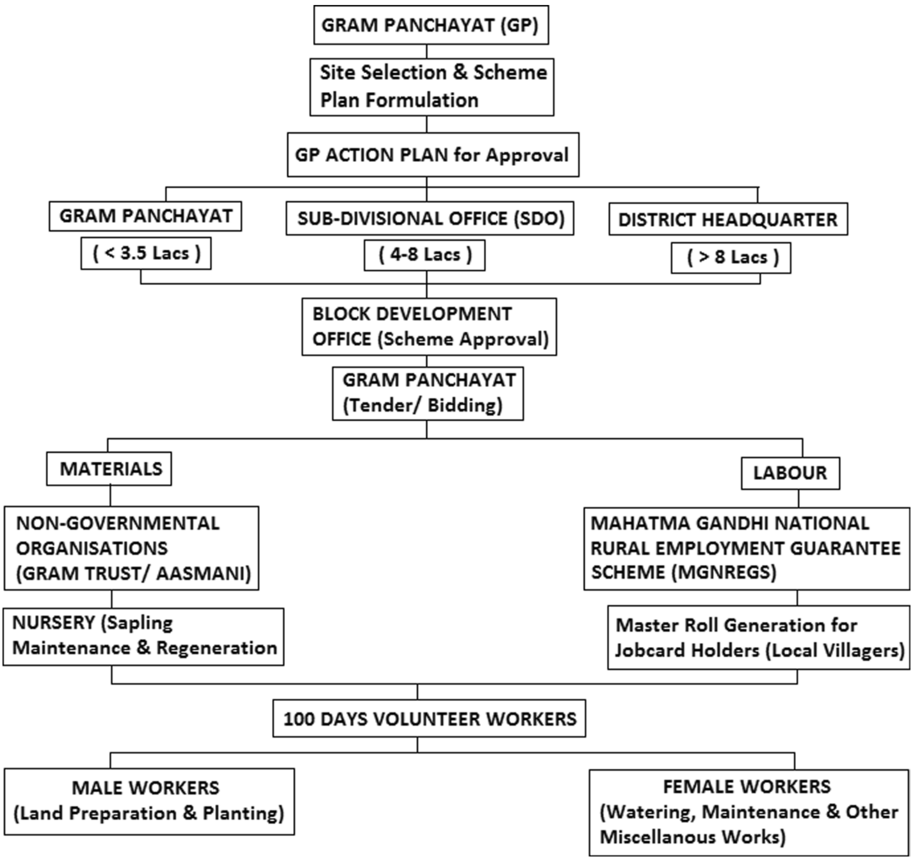

Fig. 2 Workflow for implementing a VGT-based riverbank protection scheme in rural West Bengal

Panchayats (GP—local administrative bodies comprising a number of villages), which are the authorising bodies for its design and implementation (Fig. 2). The scheme once formulated gets placed in the respective Gram Panchayat Action Plans for budget allocations and the final approval of the budget rests with the local Block Development Office (BDO). If the estimated budget is within Rupees 3.5 Lakhs (approximately US$ 5000), the Gram Panchayat straightway implements the proposed riverbank modification and VGT installation plan. The Sub-Divisional Office (SDO) undertakes examination and approval of the scheme when the budget is between Rupees 4–8 Lakhs (approximately US$ 5700–11,500) and this responsibility passes on to the District Head Office if the budget crosses Rupees 8 Lakhs. This shows the circuitous nature of the processes by which these riparian buffers are conceived and then financed. These administrative processes incur substantial time and often there are delays. This can have an impact on the feasibility of the entire scheme, as the grass needs a certain period of sustained growth before it can provide viable protection against erosion. Thus where, due to such administrative delays, the planting of the grass leaves too short a growing period (generally less than 3 months) before the monsoon strikes, results are mixed or not as effective as may have been with a longer growing period, which would have allowed the Vetiver's fibrous root system to grow deeper and anchor the soil more firmly to greater depths.

After budget approval, a tender is floated for agencies to supply the Vetiver saplings. The Group for Rural Alternative Movement (GRAM) Trust and the AASMANI Group are the two Non-Governmental Organisations (NGOs) who own Vetiver nurseries in the region and are the usual supplying agencies of these saplings. The entire procedure of material and labour supply is conducted through the MGNREGS 100 Days Work Programme. This 100-day work programme was constituted under the National Rural Employment Guarantee Act, 2005 to provide the right to work for the rural poor, and it forms the backbone for the implementation of such bioengineering schemes. While not envisaged entirely for such works, this programme provides the necessary labour and remuneration to those employed through it, to undertake the tasks of modifying the riverbank, planting the saplings and caring for them during the growth stage and is thus crucial for the success of such endeavours. As part of the MGNREGS, since its inception and full implementation, each GP across the country has been mandated to prepare a 'Master Roll' from among its villagers, of those who may be gainfully employed under this scheme as labour for any sort of development activity as permitted under the scheme (usually to do with afforestation, water conservation and drought proofing, water harvesting and irrigation works; traditional waterbody restoration and land development; flood control or rural connectivity—Ministry of Rural Development 2005). Those MGNREGS Job Card Holders who are on the Master Roll of the mouza (village) where the Vetiver planting site has been determined, are thus employed for this activity. They are appointed to oversee the entire process of fencing the area, preparing the soil, sowing the saplings, and cleaning and mulching and continuous monitoring during the early growth days, with there being gender-specific tasks of land preparation and sowing by men and watering and maintenance by women. The material and labour base is divided in a 40:60 ratio according to the MGNREGA Programme. Thus it becomes clear how a social security measure such as the MGNREGS is used in combination with a bioengineering environmental protection measure, not only to augment individual earnings but also for larger societal and ecological benefit. The inclusion of women in carrying out the relatively less laborious tasks of watering and weeding the planted riparian buffer not only enhances earnings by multiple members of a family but also encourages a larger involvement of the local stakeholders, making it a truly community-involved riverbank protection scheme.

9 Nurturing and planting specifications

Once the saplings are acquired by the GP, they are retained in a nursery and nurtured using cow dung manure so that their roots grow further in the best possible conditions. Among the various methods used for Vetiver propagation, vegetative multiplication using bare tillers is the most commonly used technique, not only because it is simple but is also cost-effective and can yield a large number of tillers from a single mother plant through root division. A tiller is a shoot growing from the base of the stem of the plant (Truong 2008). Tillers and culm slips, once uprooted, should be kept moist till they develop new root systems and thus should be planted at the beginning of the rainy season for best growth (Joy 2009). The bud multiplication technique, devised by Can Tho University, Vietnam, is basically a four-step process involving lateral bud development, multiplying new shoots and then developing new roots from the shoots to develop new plantlets in large quantities. Tissues of the Vetiver plant, especially shoot tips, young flower inflorescences and nodal buds, are used in tissue culture propagation, mostly in the horticultural industry and seldom in other sectors because of its lower cost-effectiveness. Vegetative propagation through bare shoot tillers is thus preferred over other propagation methods that need to be further developed locally (Islam 2003).

To prevent weeds and other grasses from intruding into the cleared space for planting the saplings, the soil is usually treated with an oil a couple of weeks before the grass is to be planted. This oil (which is basically a natural weed killer) consists of orange extract, clove and cinnamon essential oils, liquid soap and white vinegar. While all agencies or individuals do not use this method, it was often employed by the consulted NGOs during Vetiver planting in the study area, to ensure additional security for the grass' growth. Even without the application of this oil however, the grass' growth is usually quite uninhibited and once fully grown, the Vetiver itself is an effective weed growth inhibitor (Oshunsanya and Aliku 2017). Sample roots are usually submerged in cow dung water, for a minute, before embedding in the respective pits, and once planted, these grasses need to be watered occasionally as per the plot's soil characteristics (Mekonnen 2000). Early in the growing season, they are usually watered three to four times a week. The application of NPK Vam manure along with hydrogel, a superabsorbent material with high water holding capacity, which easily turns into a gel to store the excess water during planting, has reduced the cost of watering the plants in regions where water scarcity is a major issue. Experiments have suggested that no further watering is required after the application of this hydrogel during sowing. Geotextiles are sometimes used to cover the land once the saplings are planted. The first roots usually start developing after 3 weeks, and regular application of organic fertilisers is done up to 3 or 4 months after planting. Alternate application of vermicompost and *Jivamrit* (a special fertiliser composed of cow dung, cow urine, gram flour and Trichoderma, which is usually fermented for 4 days before applying to the soil) is used to hasten the grass' growth.

Usually, the NGOs supply the relatively inexpensive Assam variety of the Vetiver grass compared to the more expensive south Indian variety (which is native to Tamil Nadu), depending on the budgetary allocations. DNA profiling of the various cultigens has confirmed that this Assam variety of Vetiver is a related genotype of the South Indian variety, namely *Monto* and *Sunshine* (https://www.assamfloods.org/vetiver-grass-youtube/). Growing as a wild grass in Assam (Smitha et al. 2014; Behera 2018), it was traditionally used in some localities for aromatic oil production. Presently, it is grown systematically for the same purpose and the state has progressively commercialised the production of Vetiver for aromatic use (Maibangsa and Boro 2018), with the KS-1 variety released by CSIR-CIMAP (Council of Scientific and Industrial Research—Central Institute of Medical and Aromatic Plants, Lucknow) being recently promoted for commercial cultivation (http://eagri.org/eagri50/HORT282/lec11.html). However, the South Indian variety has longer roots than the Assam type (and is indeed also systematically grown in Assam for use in slope stabilisation and soil conservation due to this attribute) and thus provides better binding capacity to the soil. Past experiences from the implemented programmes in these villages suggest that excessive water logging, especially during the early growth period adversely affects the grass, particularly the Assam variety. The stagnant water takes about 2 months to completely recede from the area, and the newly planted grasses rot in this duration, if they get completely covered by silt (as also reported from studies by Truong et al. (2008) in the Mekong Delta). Thus early planting, in the winter and dry season, provides the highest chances of success in terms of grass growth and subsequent bank protection during the next monsoonal flows. Once fully grown, the grass can survive deep water flows, being able to stay submerged for up to 2 months in muddy waters (Duke and duCellier 1993; NRC 1993).

10 Riverbank modification and Vetiver grass effects on channel banks

Just prior to the nurturing period of about 2 weeks, the target reach along the riverbank is modified and reshaped to receive the plantation (Fig. 3). The land is usually sloped at an angle of 45°–60°, in which pits 15 cm in diameter and 15–20 cm deep are dug (USDA NRCS 2009). The saplings are planted in the centre of such pits so that the already minimal competition between adjacent roots due to these growing straight down, is further lessened. Once planted, the saplings needed about 4 months to mature fully, though this growth rate may get retarded in well-shaded sections (Ghosh and Bhattacharya 2018). Rainfall between 35–45 cm during these initial months gives the best results. After 6 months, the roots usually penetrate up to a depth of 60 cm, providing full anchorage to the soil. While the grass may droop in the dry season, it quickly reinvigorates during the monsoon, providing lush cover (Fig. 4).

A plant-to-plant spacing of 10 cm is optimal for proper growth of the grass (USDA NRCS 2009), as was arranged at Gholsai village (Fig. 5). The recommended row-to-row spacing varies from 45 cm for lands sloping at 35° to 30 cm for 60° slopes, to provide closer coverage along steeper profiles. Figure 6 shows the nature of bank modification done to facilitate the planting of the Vetiver at this site. Here the Vetiver grass had been planted along the outer concave right bank of the Ketia River, on which the village rests and which has been prone to erosion and undercutting. The bank, about 9 m high, was sculpted into tiered slopes, with an initial gentle upper segment of 7 m width at an angle of about 10º, and the rest being a uniformly sloping middle portion at 30° and about 18 m in length, both of these being divided into small steps, along which the saplings were planted (as surveyed in January, 2019). The lower part of the bank was supported by bamboo cuttings and some sacks of sand, which helped reinforce it further, and held the exposed soil in place while the grasses took root (e.g. Tardio et al. 2017). Once fully grown, the grass was expected to completely cover the bank and bind the soil underneath. This growth was measured initially by us just after the grass was planted and again at intervening time periods (Table 1) and the grass' growth progressed as per expected rates. The total coverage of the bank slope by the fully grown grass was observed during a repeat topographic survey of the same site

Fig. 3 Reach of the Ketia River at Shyampur village (22° 36′ 36″ N, 87° 37′ 33″ E), Ghatal Block, being prepared for planting the Vetiver buffer, **a** driving in of bamboo stakes, **b** aligning bamboo geogrids with bank geometry, **c** earth filling of the bamboo grids, and **d** a completed slope segment ready for transplantation

in January, 2020 (Fig. 7). While an extensive total station survey, as was done during the initial instance in January, 2019, was not possible 12 months later due to the bank being rendered quite inaccessible by the thick growth and for fear of trampling the full-grown grass, we were able to re-survey the original cross-section line. Comparison with the older cross-section profile reveals that the bank slope along it has actually aggraded slightly due to the Vetiver hedge accreting some of the sediments during the high flows, which have clumped in some spots locally (Fig. 6d). This was again expected since Vetiver growth has been shown to increase the hydraulic conductivity of soils (Edem and Okoko 2015), which allows greater infiltration and reduces run-off across the bank, thereby slowing down streamflow and allowing it to deposit in some patches (Edem and Oshunsanya 2014; Truong and Hengchaovanich 1997). However, the channel section on the opposite bank had been markedly eroded and sections upstream of the Vetiver-protected stretch were also similarly affected (Fig. 8), showing clear evidences of bank slumping and lateral erosion, on the outer concave bank and even on the inner convex bank. Thus, the utility and effectiveness of the VGT was proved quite clearly. Interactions during the repeat topographic survey with the local villagers further clarified this, as reports of enhanced bank stability and almost no erosion from near the stretches by their homes that are situated behind the Vetiver coverage, were obtained. However, for such success to be attained, it is crucial that the initial bank modification, nursery activities and final planting are done a minimum of 2–3 months prior to the onset of the monsoon and the usual flood season, to allow a lush grass cover over the entire bank surface and also provide time for deeper penetration of

Fig. 4 Vetiver planted along the Ketia River at Kuthighat village (22° 37′ 06″ N, 87° 37′ 26″ E) in Ghatal Block, with **a** dry appearance in the lean season, **b** lush rejuvenation during the monsoon, **c** the thick and numerous strands of a fully gown Vetiver root and **d** riverbank being prepared for transplanting the Vetiver. *Note* The photograph for **b** is courtesy the BDMO Office, Ghatal Bock and those for **c**, **d** are courtesy the GRAM Trust Organisation

the vertical fibrous roots that enhance the soil binding capacity (Tamil Nadu Agricultural University 2009).

Apart from our direct observations, in other studies too Vetiver has been known to trap sediments and reduce peak run-off and erosion along steep and unstable channel banks by approximately 64% (Dalton et al. 1996). The denser the hedges, the greater is its effectiveness. Experimental studies by Oku et al. (2014) in a farmland in Nigeria showed that Vetiver hedges could effectively reduce run-off by 7.7%, 11.5% and 11.6% when planted at spacings of 5 m, 15 m and 25 m, respectively. It was also seen that, for plots with no previous Vetiver plantings, in which soil loss was 40 times higher than the acceptable limit for tropical regions, amounts reduced to just 1.4, 6.8 and 6.5 times higher than the prescribed limit after the first planting (for the above three different plant spacings). The physical properties of the soil too get altered as a result of the robust Vetiver growth in the planted plots (Table 2). Full-grown dense hedges have been recorded as trapping up to 90–98% sediments behind the hedges and reduce run-off by up to 60–73%, with stiff erect shoots still standing 0.6–0.8 m above the water level even when the flow velocity was 3.5 m/s (Kon and Lim 1991; Xia et al. 1996; Juliard et al. 2001), and such hedges have been also been shown to trap significant amounts of pollutants (Table 3), attesting to its phytoremediative properties. For best results, such hedges are to be planted perpendicular to the direction of flow (Ndona and Truong 2011). Another instance from Vietnam has shown that

Fig. 5 Recently transplanted Vetiver saplings at Gholsai village (22° 36′ 30″ N, 87° 37′ 52″ E)—with **a**, **c**, and **d** showing different views, and with **b** denoting the sand-filled sacks and bamboo cuttings placed on the toe slope and along the bottom of the riverbank in order to protect it while the Vertiver grass grows fully

over a period of just 4 months, the soil loss reduced from 400–750 to 50–100 tons/hectare, from both the banks and the top of the river embankment (Truong et al. 2008).

11 Cost comparisons between Vetiver-based and hard engineering structures

Hard engineering measures are both capital-intensive and short-term in nature (Tucker 2010). For repairing a 1-km stretch of embankment in the study area, the costs for hard engineering measures like sandbags and riprap boulders amount to approximately Rupees 65 lakhs (approximately $93,000/–). The total cost of repairing the embankment breach along the Silabati River at Pratappur village (of length about 1.5 km) in the aftermath of the 2017 floods was estimated at Rupees 16,582,235/– (approximately $238,000/–), and this involved earth filling, ground levelling and road layering atop the embankment.

Compared to this, the components of such expenses are detailed for one such Vetiver-based scheme. Initially, the overall costs of establishing and raising a nursery (either by a NGO or by a concerned government department) amount to Rupees 2.4 lakhs (~USD 3460/–) for 100,000 Vetiver saplings (Table 4). This nursery establishment also involves a number of the local inhabitants, thereby providing a livelihood and the funds for the same are met from the MGNREGS. Tables 5 and 6 list the total cost of materials, procured saplings, planting and maintenance and labour for reinforcing a 594-m stretch of the Ketia

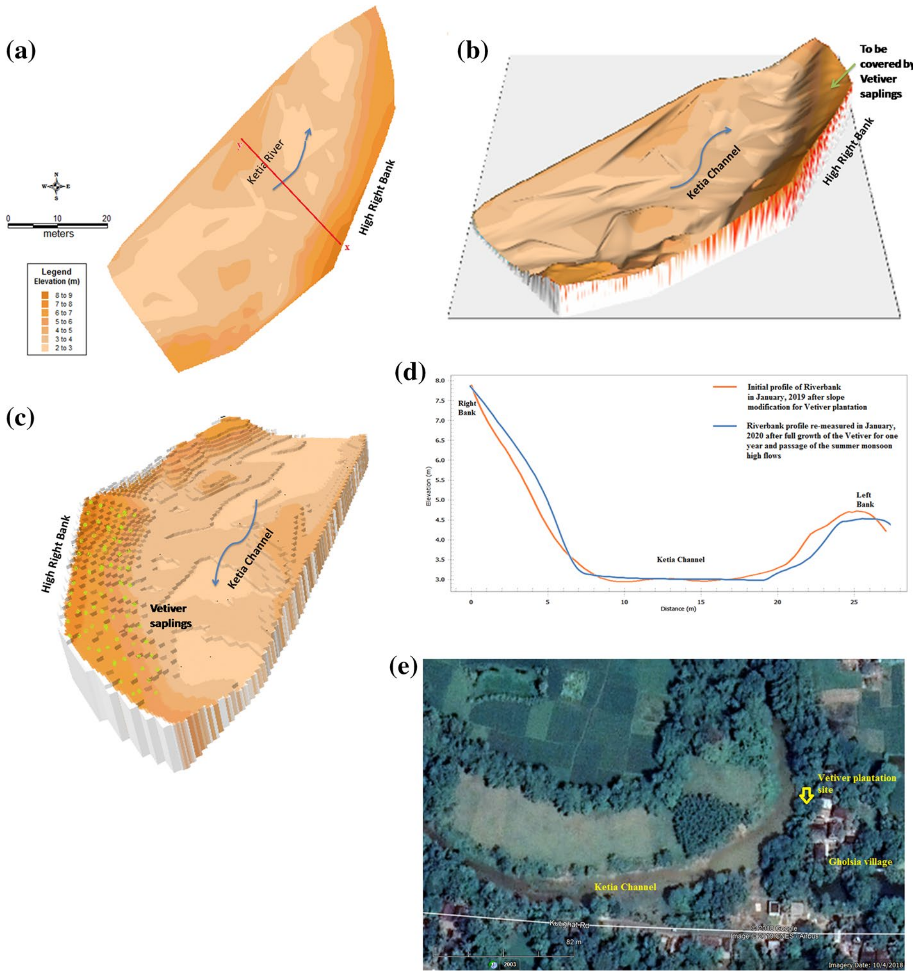

Fig. 6 Surface form of the modified riverbank at Gholsai village (22° 36′ 30″ N, 87° 37′ 52″ E) for planting the Vetiver, showing **a** bank elevation, **b**, **c** 3-D views, **d** channel cross section taken across the Ketia in January, 2019, and again across the same section in January, 2020, showing the changes in channel dimensions, with the Vetiver-protected right bank getting slightly aggraded while the left gets eroded away, and **e** Google Earth screenshot of the site

Table 1 Vetiver grass growth parameters monitored in the study area. *Source*: From samples measured by the authors and information obtained from the GRAM Trust Organisation, Kolkata (2019)

Plant portion	Growth after stated time interval from initial planting on riverbank (cm)			
	1 month	2 months	3 months	6 months
Root	26.1	40.63	66.04	100.02
Shoot	24		76.2	

Fig. 7 Views of the right bank of the Ketia (looking downstream), after the Vetiver has fully grown and covered the entire slope surface, with **a** depicting the difference between the lush Vetiver-enveloped right bank and the sparse untreated left bank and **b**, **c** showing the thick coverage and how it envelopes each part of the bank surface, including the toe slope. **b** exemplifies the remarkable stability attained by the right bank, after Vetiver growth, as the sand-filled sacks put in place during the Vetiver planting stage had not been disturbed even during the intervening high monsoonal flows

Fig. 8 Views of the unprotected left and right bank of the Ketia River at Gholsai village in January, 2020, with both banks being markedly eroded in the preceding summer monsoonal flows, showing **a**, **c**, **d** the eroded section on the concave right bank upstream of the Vetiver-protected section, even though attempts had been made to protect a portion with just bamboo stakes, but bereft of the Vetiver coverage **b** rotational bank slumping on the left bank, and **e**, **f** sections suffering marked erosion even on the inner left bank, while the opposite Vetiver-protect right bank shows much more stability

Table 2 Changes in soil physical properties with and without Vetiver. *Source*: Oku et al. (2011)

Treatment	Aggregate stability (%)	Bulk density (g/cm^3)	Mean weight diameter (mm)	Porosity (%)	Cumulative infiltration (cm/100 min)
Vetiver plots	64	1.3	1.6	51	90.7
Bare soil	56	1.4	1.3	47	54.9

Table 3 Dry and wet weights of contaminants collected from the Vetiver and bare sections of a drain after harvest. *Source*: Carlin et al. (2003)

Treatment	Vetiver plot	Bare plot
Total dry weight (kg)	0.5	25.2
Total wet weight (kg)	2.5	126.0

channel at Gholsai village using the VGT, which came to Rupees 799,191/– (approximately $11,500/–), and again provided employment to 120 people. Thus the overall cost of nursery establishment and full implementation of this grass-based riverbank scheme is shown to be far below that of hard engineering structures. Moreover, some of the costs entailed in the VGT above are initial one-time costs, and therefore, subsequent implementation can feasibly occur at futher reduced expense.

While it may be unfeasible that the entirety of the riverbank can be managed simply through live vegetation methods, the high costs and relatively short lifespan of the oft-preferred structural measures necessarily entails a relook at policies that advocate only hard engineering methods. In comparison, bioengineering techniques are much more sustainable and eco-friendly and practical applications have suggested that a bioengineered 1 km stretch can yield comparable or better results than its structural counterparts, with only few months old Vetiver plantations on filled earth sections of embankments having previously been recorded to hold back water depths of over 3 m and also survive more than a month in the submerged state (NRC 1993), apart from reducing the cost by almost 70%. Furthermore, field and flume experiments using the Vetiver grass have demonstrated its effectiveness in retarding flow velocities and thereby preserving riverbanks, as can also be ascertained from other case studies across India (Truong 1999b, 2017), apart from those examined here. Therefore, a combination of hard and soft methods, based on site requirement and priority, might well be the way forward for judicious resource utilisation and long-term riverbank stabilisation.

12 Local perception of Vetiver-based riverbank protection schemes

A brief questionnaire survey was conducted among the residents of three villages where the VGT method has been implemented in the study area. All respondents agreed that the grass was effective in protecting riverbanks, its deep roots mitigated soil loss and that they would readily recommend it to other villages. However, their only interaction with the grass was at the planting and rearing stage, as labourers (that too, only for those who were Job Card Holders) since all decisions pertaining to site selection and design were taken

Table 4 Nursery cost estimate for raising 100,000 Vetiver Saplings under the MGNREGA scheme. *Source*: GRAM Trust Organisation, Kolkata (2019)

S. no.	Description of items	No. of man-days	Unit	Rate/labour (in Rs.)	Total amount (in INR)	Total amount (in USD)
(A) *Labour component*						
1	Cleaning and demarcation of mother bed	4	Nos	176	704	10.15
2	Preparation of mother bed including ploughing, tillering, levelling and weeding	20	Nos	176	3520	50.75
3	Nursery of mother slips	60	Nos	176	10,560	152.25
4	Separation of slips from mother slips and transplanting in poly pack. @ 350 nos. of saplings for 1 unskilled labourer	286	Nos	176	50,336	725.73
5	Preparation of soil for poly pack	50	Nos	176	8800	126.88
6	Nursery of slips (including watering, cleaning and weeding)	300	Nos	176	52,800	761.26
7	Filling of poly packet with soil	286	Nos	176	50,336	725.73
8	Fencing of the nursery field	15	Nos	176	2640	38.06
9	Watcher for 2 months (1 unskilled labourer/day)	60	Nos	176	10,560	152.25
Total					190,256	2743.06
S. no.	Material	Quantity	Unit	Rate	Total amount (in INR)	Total amount (in USD)
(B) *Material component*						
1	Cost of planting material (only required the first time)	10,000.00	Nos.	2.50	25,000	360.44
2	Cost of poly pack	50.00	Pack/kg.	200	10,000	144.18
3	Cost of supervisor (25 man-days = 1) (semi-skilled person)	41.00	Nos	261	10,701	154.28
4	Cost of fencing materials like coir ropes and bamboos	20.00	Nos	200	4000	57.67
Total					49,701	716.58

Total project cost for labour and material component = Rs. 239,957/– (~ USD 3459.64)

Amounts in INR have been converted to equivalent sums in USD on basis of the conversion rate on 15.04.2019

Table 5 Cost of unskilled labour and wage components for the Vetiver plantation along the Ketia Channel at Gholsia village. *Source*: Dewanchak-II Gram Panchayat Office, Ghatal Block, Paschim Medinipur District, West Bengal

S. no.	Description of items	Output of work/ man-days	Total quantity				Unskilled labour (in person)	Rate (in INR)	Total amount	
			Nos.	Length (m)	Breadth (m)	Quantity			INR	US $
1	Survey and demarcation	75 m/unskilled labour	1	594		594 m	7.92	191	1512.72	21.81
2	Initial cleaning of site by cutting and removing bushes and weeds	50.00 sq m/unskilled labour	1	594	9	5346 sq.m.	106.92	191	20,421.72	294.48
3	Labour for slope preparation and planting	5.00 sq m/unskilled labour		594	9	5346 sq.m.	1069.2	191	204,217.2	2944.84
4	Collection of local *Ipomea* (minimum length 4ft)	150 unskilled labours				59.4 nos.	0.4	191	75.64	1.09
5	Planting *Ipomea* bars	50 unskilled labours				59.4 nos.	1.19	191	226.91	3.27
6	Planting Vetiver saplings	150 saplings/ unskilled labour	120,841			120,841 nos.	805.61	191	153,871.51	2218.85
7	Labour required for fencing the site	10 m/unskilled labour				612 m	61.2	191	11,689.2	168.56
8	Labour for first cleaning, mulching and cutting works					594 m	11.88	191	2269.08	32.72
9	Labour for second cleaning, mulching and cutting works					594 m	11.88	191	2269.08	32.72
10	Labour for third cleaning, mulching and cutting works					594 m	11.88	191	2269.08	32.72
11	Labour for fourth cleaning, mulching and cutting works					594 m	11.88	191	2269.08	32.72
12	Regular watering, maintenance and miscellaneous works by self-help groups	1 unskilled labour/500 m				120 nos.	142.56	191	27,228.96	392.65
	Total wage component cost =						2243		42,8413	6177.77

Amounts in INR have been converted to equivalent sums in USD on basis of the conversion rate on 15.04.2019

Table 6 Costs of material components for the Vetiver plantation along the Ketia Channel at Gholsia village. *Source*: Dewanchak-II Gram Panchayat Office, Ghatal Block, Paschim Medinipur District, West Bengal

S. no.	Description of items	Total quantity	Rate (INR)	Total amount	
				INR	US $
1	Cost of plant	132,925 nos.	2.5/sapling	33,2312.5	4791.99
2	Cost of water pot for irrigation	6 nos.	200 each	1200	17.30
3	Fencing of site using bamboo nails and wires	612 m	15 m	9180	132.38
4	Supervision of work (counting of wage labourers, taking attendance in master roll and other miscellaneous works)	90 nos.	286.50/semi-skilled labour	25,785	371.82
5	Display of permanent signboard	1 nos.	2300/board	2300	33.17
	Total material component cost =			370,778	5346.67

Amounts in INR have been converted to equivalent sums in USD on basis of the conversion rate on 15.04.2019

solely by the respective Panchayats and they were simply directed as to the labour requirements. No prior awareness camps were conducted regarding the further/allied uses of this grass (in terms of its combination with other crops or pertaining to the extraction of other Vetiver-based products), or even if these had been briefly mentioned, nothing had as yet materialised. With the common villager primarily looking at the scheme as a means of employment and wishing to be associated with it since it was a government-mandated project, suggestions as to how this technology could be improved or made more site specific were not forthcoming, with most simply stressing that their daily incomes had risen from it as the MGNREGS programme was attached with this endeavour. Some did opine that they preferred a combination of the Vetiver grass with structural measures such as guard walls and boulder pilings along the most erosive and flooded tracts.

13 Conclusion

The VGT system is a most suitable bioengineering solution for combating eroding riverbanks due to:

- Its ability to withstand climatic extremes and grow across the tropical and subtropical world.
- Cost-effectiveness, self-resilience and non-invasive nature, all of which are vital considerations in developing nations where capital resources are scarce and land and water degradation problems are acute (Howell 2008).
- Potential ability to provide long-term support for erosion control and soil conservation (as is apparent from numerous examples across the world), especially in regularly flood and bank erosion affected areas (Budinetro 2019).
- Practical field experiences of this grass absorbing up to 2.5 kg carbon per year (Chomchalow 2003a), with prospective plans of employing its phytoremediation properties towards reducing the effluent pollution into the River Ganga by planting it along high drains.

- Its other myriad economic benefits, in terms of fodder, fuel and use for handicrafts (Chomchalow 2003b; Nanakorn and Chomchalow 2006), which can generate income in rural pockets, like those in West Bengal, wherein Self-Help Groups (mostly comprising of female workers) manufacture various bags, folders and scrubbers from the grass' roots.

However, some drawbacks exist before VGT implementation can achieve its full potential in the study area, wherein the aromatic importance of this grass and the high value its oil can fetch has scarcely been explored. For this, knowledge dissemination to the lowest tier of society and involving the local community is paramount (Islam 2016), along with the overcoming of such scenarios where village-level stakeholder engagement has been only partial, as was the perception gained from the surveyed villagers, who have been only involved as labourers in setting up the riparian buffers for streambank protection and have not received any further guidelines or instructions on how the plant can be harvested and utilised for its additional economic benefits.

The detailed infrastructural framework and the institutional mechanisms involved in setting up such a programme also require more smooth and swift coordination between government departments, NGOs and different tiers of administration. When delays in sourcing the grass from the nursery have occurred or it has been transferred to the riverbank without allowing an adequate growing period before the monsoon, the grass' effectiveness has been severely hampered. The MGNREGS programme has provided a vital lifeline in supplying ready labour for undertaking such projects, and the numbers of such flood control schemes have steadily grown over the years. Most western nations have large environmental organisations and dedicated agencies that design, coordinate and execute such bioengineering plans and also have long histories of such endeavours (Evette et al. 2009). Here (i.e. in India overall and in southern West Bengal in particular), such plans are more piecemeal and designed and implemented almost entirely by the local communities and administratively lower-level government departments, without much inter-block or inter-district coordination, following disparate avenues and means of bringing together the labour, materials, saplings and funds to see a project through. Thus knowledge base and best practices transfer issues come to the fore, compounded at times by poor documentation and the lack of long-term monitoring, and possibly restrict the full benefits that such endeavours could otherwise elicit. Handbooks from the country's nodal river agency, the Central Water Commission, scarcely contain elements of bioengineering or Vetiver-based bank protection guidelines, being still steeped in the utilisation of structural measures for this purpose. However, the marked success of such vegetation-based schemes and the recent spurt in their implementation holds out hope of more sustained and far-reaching bioengineering schemes for riverbank protection being devised in this region.

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Data availability All data and information presented in this paper are available in the public domain, either on websites or in the relevant reports published and prepared by related government offices and non-governmental organisations.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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