Final Report

Development of value-added products from water hyacinth to support alternative livelihoods and ecological resilience in coastal villages of southwest Bangladesh

Blue Gold Innovation Fund
Blue Gold Programme, Bangladesh

Dr. Md. Nazmul Ahsan
Professor, Fisheries & Marine Resource Technology Discipline
Khulna University, Khulna 9208, Bangladesh; and
Principal Investigator, BGIF-KU WH Project

25 November 2020

Disclaimer

This study received funding from the Blue Gold Innovation Fund (BGIF) of Blue Gold program supported by the Royal Netherlands Embassy in Dhaka, Bangladesh and implemented by Mot Macdonald. The data, information and the views expressed in this report are exclusively of the authors of this report. Neither the Royal Netherlands Embassy in Dhaka nor the Blue Gold Program in Bangladesh or ts implementing organization, Mot Macdonald assumes any kind of responsibility of the accuracy of data, information and views presented in this report. Financial support of the BGIF to this study is in no way can be interpreted as any sort of endorsement by the Royal Netherlands Embassy in Dhaka, the Blue Gold Program in Bangladesh or its implementing organization Mot Macdonald of any of the views expressed in this report.

List of Contents

List of Figures

List of Tables

Acknowledgments

The authors of this report acknowledge with appreciation the cooperation of the Blue Gold Program Bangladesh for their support in many ways to the accomplishment of this pilot project. Especially, the generous support and encouragement received throughout this project from Mr. Guy C. Jones, Team Leader, Blue Gold Program in Bangladesh are gratefully acknowledged. Ms. Judith de Bruijne, the then Innovation Fund Manager of Blue Gold Innovation Fund (BGIF) spent hours discussing about the concept of turning water hyacinth problem into a business proposition. We gratefully appreciate her insights, critical comments and helpful suggestion that led to the development of a full proposal and subsequent approval by BGIF. We acknowledge the cooperation of Mr. Maurits Bosman during implementation of this pilot project. The excellent courtesy and cooperation provided by Mr. Tanvir Islam, Joint Manager, BGIF during the entire course of this study and the critical comments and suggestions, particularly with regard to market development issues provided by Mr. ASM Shahidul Haque, SVC Workgroup Leader are also gratefully acknowledged.

Water management group of Polder 25 in Thukra, Dumuria, Khulna deserves true appreciation for their time and interest and for their active participation throughout the entire project for successful implementation of this pilot project. Special thanks are due to Prokritee, which allowed us to visit its handmade paper manufacturing facilities and to observe their products, as well as for briefings on handmade paper market. We express our sincere gratitude to the participants who attended various consultation meetings, workshops and events throughout the project to provided valuable comments and suggestions.

The sincere help and cooperation provided by Mr. Nazrul Islam, Head, Drawing and Painting Discipline, Fine Arts School, Khulna University to organize a virtual art competition during Covid-19 situation are gratefully acknowledged. At last but not the least, we would like to express our sincere gratitude and heartfelt thanks to the honorable Vice Chancellor of Khulna University for his kind approval and cooperation for successful implementation of this study.

Note

The pilot project was implemented by a team of faculty members from different academic disciplines of Khulna University. Led by Prof. Dr. Md. Nazmul Ahsan of Fisheries and Marine Resource Technology Discipline as the Principal Investigator, the project team members included Prof. Dr. Md. Nazrul Islam of Forestry and Wood Technology Discipline and Prof. Dr. Md. Nur Un Nabi of Business Administration Discipline as the Co-Principal Investigators. Graduate students and research assistants from these Disciplines were involved in laboratory works, data collection from field and piloting activities with the polder community members as well as arranging and facilitating a series of meetings and workshops.

Acronyms and Abbreviations

Abridged form	Elaborated form
BG	Blue Gold
BGIF	Blue Gold Innovation Fund
CEP	Coastal Embankment Project
FGD	Focus Group Discussions
GSM	Gram Square Meter
KII	Key Informant Interview
KU	Khulna University
WH	Water hyacinth
WH-B	Water hyacinth with black liquor
WH-C	Water hyacinth with cow dung
WH-O	Water hyacinth only
WMG	Water Management Group
WUR	Wageningen University and Research

Executive Summary

Coastal zone of Bangladesh is quite distinct and tropical in nature and was once regarded as one of the most productive ecosystems of the world due to regular flush of nutrient rich silts and supply of organic matters from mangrove litter falls. Over the last few decades, however, changes in land use pattern in the coastal districts such as construction of embankments and transition of rice to shrimp farming had brough unintended but inevitable consequences on the livelihoods of millions. Given that the polders were not tuned to withstand current and future extreme climate events the livelihoods of the coastal community are at stake. Salinity intrusion, lack of fresh water, drainage congestion and prolonged water logging creating habitat for growth and spread of water hyacinth (WH) in the polder areas are causing loss of crops and income, reduced food security and explains in part the higher than average poverty levels in the coastal districts, particularly in the southwest ones.

Water resource management is central to the socioeconomic development and environmental sustainability of the southwest polder districts. In this regard, eradication of WH from coastal polder areas offers multiple societal and environmental benefits as being globally referred to as a 'menace' WH clogs the canal water flow, creates barrier in the water flow at the intersection between river and canal, decreases native fish population and makes water unsuitable for various productive use. Global experiences of eradicating this aquatic weed through physical, mechanical, biological, or chemical means provide little hope. However, past research conducted by Khulna university has successfully developed the prototypes of craft paper from stems and nutrient rich fertilizer from the leaves and roots of water hyacinth. To showcase the feasibility of producing these valuable products from an otherwise nuisance species in field context, the current project implemented with members of Water Management Group (WMG) under Polder 25 in Thukra, Dumuria, Khulna.

At the outset, reconnaissance, site visits, focus group discussions and planning meetings were undertaken that set the stage for understanding the problems posed by uncontrolled growth and spreading of water hyacinth on the coastal community's lives and livelihoods, with particular emphasis on its resource potential and community mobilization to realize the potential. Subsequently, adapting laboratory prototype to field condition was carried out. For this purpose, the collected fresh water hyacinth was chipped and dried partially before pulping. Potassium hydroxide (KOH) was used for pulping. Bleaching powder was used for bleaching the pulp and hand sheet was made using the locally fabricated machineries. The collected black liquor was mixed with compost to improve the compost quality using earthen pits prepared on site by the community under the supervision of the experts.

The pilot project had two components with production of pulp for craft paper as the main component while production of compost using process by-products as an added component. The leaves and roots of the collected fresh water hyacinth was removed and the petiole was chipped and air dried. The plant materials were then cooked using KOH for producing pulp while bleaching powder was used to make the pulp white and bright. Finally, the handmade craft paper was produced from the both bleached and unbleached pulps using the locally fabricated machineries. On the other hand, the collected black liquor was mixed with the water hyacinth leaves, roots and whole fresh one to make compost rich in potassium and other macro nutrients.

After optimizing the process condition, it was found that the highest yield was obtained at around 33% when the alkali charge and cooking time were 10% and 2 hours, respectively. The brightness, tear and tensile indices of WH craft papers were also found to be within acceptable limits This optimized condition was practiced at the project piloting site and hand sheet was produced from both bleached and unbleached pulps. The WMG members successfully produced hand sheet of different qualities using the locally fabricated machineries. Meanwhile, compost produced with water hyacinth supplemented with cow dung appeared to be best in terms of various physicochemical parameters of the compost. The unused leaves and roots of WH are naturally rich in nitrogen but inclusion of pulp process waste, called black liquor, also contributed to increased potassium content of the final compost as potassium hydroxide was used for digestion of raw WH stems.

The prototype piloted through participatory approach with WMG does not require any costly equipment and chemicals, which means this technology can easily be adapted at wider polder community level. The pilot project successfully demonstrated on-site pulp production from WH through a participatory approach, produced craft paper from the pulp using simple hand held pressing machines by community members, utilized the by-products for compost production in combination with other locally available agricultural wastes and identified some avenues for market linkage. Through market feasibility study, a 'Business Model Canvas' was developed by identifying the necessary business processes, cost structure, revenue streams and key activities for successful entry into existing and new markets. The market feasibility study also identified challenges that could possibly be faced by the polder community including competition from established business houses who rely on handmade paper imported from overseas countries. Diversification of products made from WH craft papers and keeping price competitiveness remain major challenges for sustainable marketing necessary for community entrepreneurship development in WH business piloted and described in this report.

The on-site pulp and compost production techniques will negate the necessity of unsustainable chemical or impractical mechanical cleaning of WH for off-site dumping which often

contaminates new water bodies. Apart from being environment friendly, the ingenuity of this model lies within the fact that it addresses the alternative livelihood issues of poor coastal community where an apparent value and thus demand for WH will provide necessary impetus for small cottage industry development while eradication of WH on a sustainable basis will provide multiple other socio-economic and environmental benefits.

Issues and challenges that still need to be addressed to ensure sustainability include change in or enacting of new management strategies and action plans regarding the complexity of control options and the potential for climate change to help spread water hyacinth. Backed by national program and policy, local government institutions should come forward to mobilize resources so that polder communities and other stakeholders become aware that WH not only creates havoc on environment but also offers opportunity for income. To realize this, piloting similar projects in other polder areas involving more WMGs has been suggested to bring a real change in the psyche of the people living in the actual condition in the polder areas of southwest coastal districts and elsewhere in Bangladesh.

Stakeholder consultations at various stages of project implementation raised some interesting research questions that need to be answered to address WH challenge on a sustainable basis including mass balance study of WH, impact of eradication of WH the customary livelihoods, ecosystem and aquaculture. Research should also be carried out to understand how further land use and land cover changes in the dynamic delta under the climate change regime will affect the proliferation and propagation of WH in natural waterbodies of southwest coastal Bangladesh. The report ends with a caution that a few months of piloting activities involving only one WMG may not be sufficient to optimise the impact of project results, to ensure sustainability and to realize the scale up and scale out potential of this business model. Unlike product development and piloting marketing of products require more systematic and concerted efforts and for this continuity is of paramount importance. It was hoped that as the Blue Gold Program phases out, other would follow the suit for sustaining the momentum achieved, particularly with regard to demand creation of WH based eco products.

1. Contextual Overview

1.1. Country context

Being part of the world's largest river delta[1] Bangladesh is blessed with numerous rivers, streams, and canals that have been supporting diverse agriculture activities for the lives and livelihoods of people living on this soil. The delta is known as the Ganges-Brahmaputra-Meghna Delta, named after the three mighty trans-boundary rivers that discharge about 43,000 m^3/s alluvial fluids averaged over the year into the Bay of Bengal[2]. Owing to the deltaic formation of Bangladesh and the related interface with the vast river networks, the Bay of Bengal and climate change the delta is also, in its most inclusive sense, known as the Bengal delta[3]. Out of the world's 500 million delta-living people, over one fifth live in the Bengal delta[4], which is bounded in the north by the Ganges floodplain and in the south by the Sunderbans mangrove forest, the world's largest single-tract mangrove forest. With increasing population pressure in the backdrop of an agrarian economy, land and water had always been the two most precious natural resources of this dynamic delta.

Currently, Bangladesh remains one of the most densely populated countries of the world with over 160 million people living on a relatively small land of 147,570 sq. km. Together with high population density, the unique geographic location, low elevation from the sea and overwhelming dependence on nature make it highly vulnerable to climate change and anticipated sea level rise. This is particularly the case for the costal districts. According to the Coastal Zone Policy 2005 of the Government of Bangladesh, 19 districts out of 64 are in the coastal zone covering an area of 47,201 sq. km., which is 32% of total landmass of the country (Fig. 1). These coastal districts, particularly the 12 exterior ones[5], are characterized by a delicately balanced natural morphology of an

[1] Gupta, A. (2007). Large Rivers Geomorphology and Management. Chichester, U.K.: Wiley, 689p.

[2] Chowdhury, K.R. and Bhuiya, A. (2000). "Environmental processes: Flooding, river erosion, siltation, and accretion-physical impacts," in A.A. Rahman, S. Huq, and G.R. Conway (eds.), Environmental Aspects of Surface Water Systems of Bangladesh, Dhaka, Bangladesh: The University Press Limited.

[3] BDP (2018). Bangladesh Delta Plan 2100, Planning Commission, General Economics Division, Government of the People's Republic of Bangladesh.

[4] Ayeb-Karlsson, S., Geest, K., Ahmed, I. Huq, S. and Warner, K. (2016). A people-centred perspective on climate change, environmental stress, and livelihood resilience in Bangladesh, Sustain Sci, 11:679–694.

[5] Islam, M.R. (ed.). (2004). Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh, PDO-ICZM, The University Press Limited, Dhaka, Bangladesh.

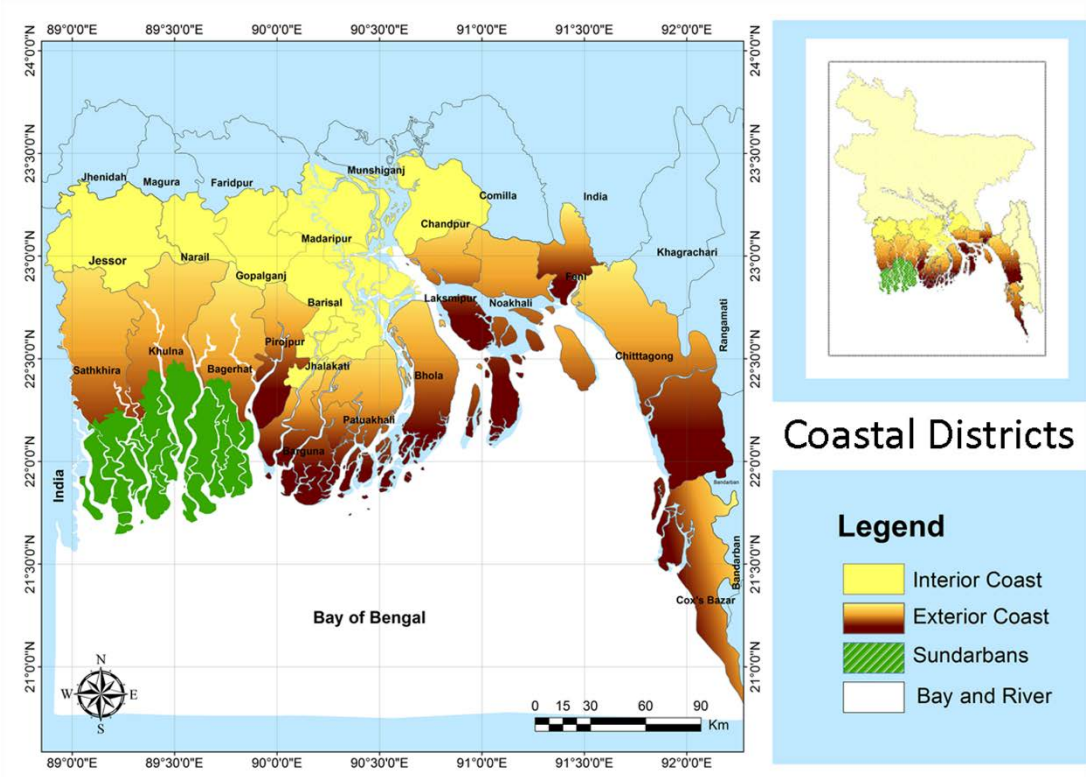

Fig. 1. Map of Bangladesh showing the exterior and interior districts relative to the Bay of Bengal and the Sundarbans mangrove forest

evolving flat delta, which is subject to very high tides and frequent cyclones from the Bay of Bengal encountering very large sediment inflows from upstream. On a positive note, the ecosystem of the coastal zone of Bangladesh is quite distinct and tropical in nature. Characterized by tidal flats, natural levees and vast mangrove swamps, the coastal zone of the country, particularly the southwest coastal zone, is regarded as one of the most productive ecosystems of the world due to regular flush of nutrient rich silts and supply of organic matters from mangrove litter falls.[6] Over the last few decades, however, changes in land use pattern in the coastal districts have been dramatic; the most important one being the construction of embankments to boost rice production with its unintended but inevitable consequences.

1.2. Coastal polder context

During 1960-70s, the Coastal Embankment Project (CEP), implemented largely by Dutch engineers, built mud embankments; popularly known by its Dutch term 'polder' in Khulna, Bagerhat, Satkhira and other coastal districts to protect the coastal lands from

[6]Winston et al., (2010). Climate change risks and food security in Bangladesh, World Bank, Washington, D.C.

tidal inundation and flooding, and to increase rice production[7]. By 1980s, polders became part of the natural setting of coastal Bangladesh with a network of nearly 5,700 km long embankments in 139 polders[8]. Coastal polders brought 1.2 million hectares of land under agriculture or aquaculture and provided protection of lives and properties of coastal communities against flood, storm surge and salinity intrusion[9]. Eventually, it was no longer financially viable to cultivate rice because the polders had become waterlogged while shrimp farming appeared to be more lucrative. This has brought another major change in land use pattern in the coastal districts: crop farms were converted to shrimp farms within the polders defying the purpose for which these were meant for and jeopardizing coastal ecosystem and the livelihoods of the coastal communities.[10]

With climate change impacts being no longer an anticipation but a reality the resilience to natural shocks of coastal communities living within the polders are increasingly at stake. Salinity intrusion, lack of fresh water, drainage congestion and prolonged water logging in the polder areas are causing loss of crops and income, reduced food security and explains in part the higher than average poverty levels in the coastal districts. This is particularly the case for southwest coastal districts as the poverty rate in this coastal area remain largely unchanged since 2010.[11] Similarly, seven of the 12 districts in the highest quintile of extreme poverty are coastal[12], as are four of the 10 districts in the highest quintile for the percentage of severely undernourished children[13].

Such disparity can be explained by the fact the coastal communities are left with none but fishing and aquaculture related activities to maintain their livelihoods due to past anthropological events that drastically changed the land use pattern in the hydrodynamic delta. Although shrimp aquaculture was a mean of transition it lacked a

[7] The CEP formally ran from 1961 to 1979. Other projects involved in embankment construction in coastal districts include the Delta Development Project during the 1980s and most recently completed Asian Development Bank-funded Coastal Rehabilitation Project.

[8] Islam, M.R. (ed.). (2004). Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh, PDO-ICZM, The University Press Limited, Dhaka, Bangladesh.

[9] *Ibid* 3.

[10] Ahsan, M.N. (2009). Community-Related Social Issues in Shrimp and Prawn Farming in Bangladesh, WorldFish Center, Penang, Malaysia; and references cited therein.

[11] *Ibid*

[12] Bangladesh Bureau of Statistics, World Bank and World Food Program (WFP). Bangladesh Poverty Maps, 2014.

[13] WFP, 2012. Indicators based on the 2012 Bangladesh Child and Mother Nutrition Survey and the 2011 Health and Morbidity Status Survey.

development framework, which further aggravated the already fragile ecosystem of the polder areas.

Therefore, the government has recognized the need for participatory water management and diversified agricultural production within the polders as an important transition pathway to sustainable economic development necessary to eliminate regional disparity. Development partners also began to invest more in the water management and show an enhanced awareness of the interconnectedness of social and ecological systems and consequently launched various projects with the main objective to increase coastal productivity by improving capacity of local communities and institutions to manage coastal resources in a sustainable and equitable fashion.

1.3. Study context

Given that the polders are not resilient, nor tuned to withstand current and future extreme climate events the livelihoods of the coastal community are becoming far more vulnerable than before. By developing local capacity to manage water resources, diversified agricultural production and inclusive markets climatically stressed polder communities will be able to progressively increase income and reduce poverty. Hence, the Governments of Bangladesh and The Netherlands undertook Blue Gold Programme, which is being implemented in 22 polders in four southwest coastal districts. With a program level goal *to reduce poverty of selected coastal polders by creating a healthy living environment and a sustainable socio-economic development*[14] Blue Gold (BG) aims to reduce poverty and improve food security through equitable water management and strengthened value chains.

To accelerate the development process in the Program area, BG has identified several cross-cutting themes and innovations which, according to BG Program Document[15], *will promote the introduction and application of innovations, both technological as well as conceptual innovations, as long as they are of clear relevance for the beneficiaries of the Program and the concerned implementing agencies in Bangladesh. Such innovations can be found in other projects and organisations working in Bangladesh, but also specifically with Dutch knowledge institutions and private sector enterprises.* Accordingly, the Blue Gold Innovation Fund (BGIF) was created for water management and productive sector issues.

[14] http://www.bluegoldbd.org/what-we-do/about-blue-gold/ (accessed on 20 Nov 2020)

[15] Procedure Manual for Blue Gold Innovation Fund, 2017, Mot Macdonald, 17p.

Under its water management sector BGIF identified multifaced problems caused by water hyacinth in the polder areas and to solve this problem BGIF signed an agreement with Khulna University on 29 January, 2019 to pilot a business case with polder community. Accordingly, faculty members from different Disciplines of Khulna University (KU) with excellent track of experiences working with coastal polder communities carried out the piloting study in collaboration with expert(s) from Wageningen University and Research (WUR), the Netherlands during February 2019 through October, 2020. This report describes the objectives, scope, methodology and results, and outputs achieved of the aforementioned pilot study entitled, "Development of value-added products from water hyacinth to support alternative livelihoods and ecological resilience in coastal villages of southwest Bangladesh."

Structure of the report

This report is organized into nine sections. Following the general context that summarizes the evolution of dynamic delta of Bangladesh with brief historical context of coastal polders and their consequences, the second section provides state-of-the-knowledge on the distribution of water hyacinth and its global and local impact that affects the lives and livelihoods of coastal community in many ways and that sets the stage for this pilot project as described in section three. In this section, the rationale, goal, objectives and approach of the project are described. The fourth section presents the project description including pilot site selection and planning and inception activities including a brief on business development activities that was undertaken in parallel to this pilot project.

The next two sections were at the core and the most substantial activity of this pilot project. The fifth section describes activities that entailed optimization of laboratory prototype to suit community-based production system for the production of craft paper and compost from water hyacinth whereas the sixth section deals with development of those products by the polder community at the pilot site. A series of capacity building trainings that enabled community members to produce value-added products from water hyacinth are described in seventh section.

With a summary on the activities performed and results achieved and concluding remarks on lessons learned in eighth section, the final section provides a set of recommendations that are believed to have important bearings on the sustainability of the project's achievements and impacts realized so far.

2. Background of the project

2.1. General information on water hyacinth

Water Hyacinth (*Eichhornia crassipes*) is a free-floating aquatic macrophyte in the Pontederiaceae family. The beautiful, large purple and violet flowers of this plant (Fig. 2) cannot hide the fact that it has been labelled as the world's worst aquatic weed and has garnered increasing international attention as an invasive species.[16,17] It is an erect floating herb that reproduces both vegetatively, via ramets formed from axillary buds on stolons, and sexually through seed production.[18] The aquatic plant originates from the Amazonia, Brazil [19] and probably Argentina[20], with anthropogenic spread to most of the tropical and sub-tropical countries of the world as shown in Fig. 3.

Fig. 2. Flower of a water hyacinth plant

The widespread occurrence of WH is mainly due to combination of its unique biological characteristics, global warming and exacerbated eutrophication of surface water.[21] It has been carried by tourists, plant collectors and botanists because of its beautiful blooms and foliage[22] and is currently established in the natural environments of at least 62 countries.[23]

[16] Téllez, T., Lopez, E., Granado, G., Pérez, E., Lopez, R. and Guzmon, J., (2008). The water hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). Aquatic Invasions, 3, 42-53.

[17] Holm LG, Plunckett DL, Pancho J.V., Herberger JP (1997) World's worst weeds. Honolulu: University of Hawaii Press.

[18] Forno IW, Wright AD (1981) The biology of Australian weeds. 5. Eichornia crassipes (Mart) Solms. Journal of the Australian Institute of Agricultural Science 47: 21–28.

[19] Barrett SCH, Forno IW (1982) Style morph distribution in new world populations of *Eichhornia crassipes* (Mart.) Solms-Laubach (water hyacinth). Aquatic Botany 13: 299–306.

[20] 14. Wilson JR (2002). Modelling the dynamics and control of water hyacinth, *Eichhornia crassipes* (Martius) Solms-Laubach: Imperial College London (University of London).

[21] Yan, S., & Guo, J. Y. (Eds.). (2017). Water hyacinth: environmental challenges, management and utilization. CRC Press.

[22] Kriticos DJ, Brunel S (2016) Assessing and Managing the Current and Future Pest Risk from Water Hyacinth, (Eichhornia crassipes), an Invasive Aquatic Plant Threatening the Environment and Water Security. PLoS ONE 11(8): e0120054. doi:10.1371/journal.pone.0120054

[23] *Ibid* 20.

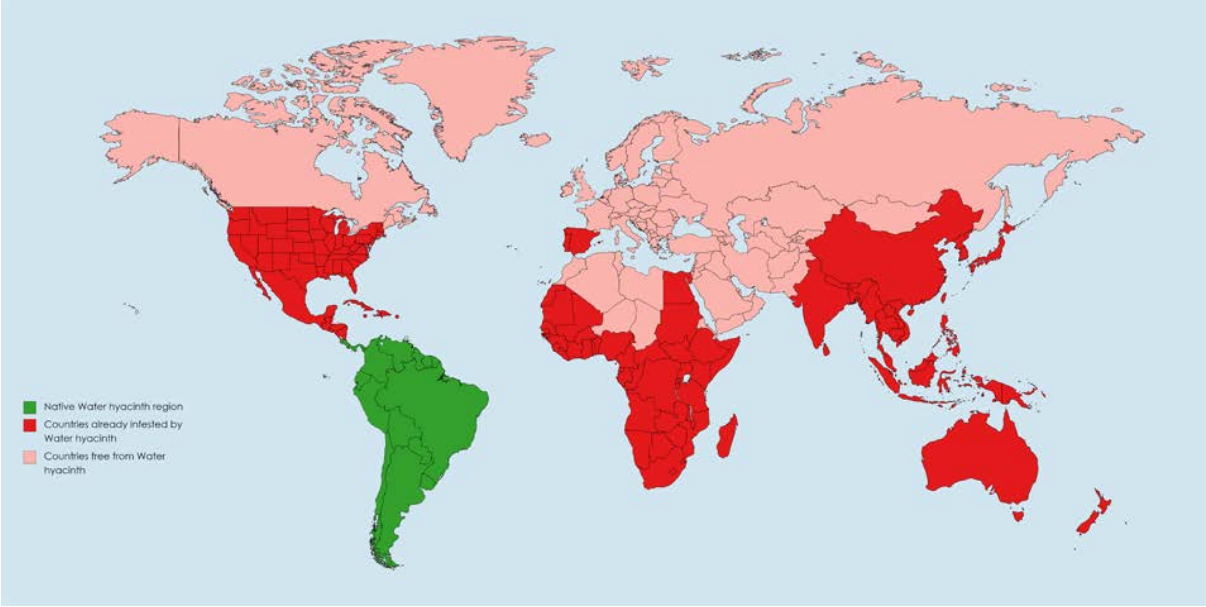

Fig. 3. Global map showing the distribution of water hyacinth. Redrawn from Téllez et al (2008).[24]

The weed reproduces extremely quickly by producing daughter plants on stolons; 10 plants can produce a mat of 650,000 plants in one growing season.[25] Each plant additionally can produce thousands of seeds each year, and these seeds can remain viable for more than 28 years.[26] They are vigorous growers and mats can double in size in one to two weeks while,[27] in terms of plant count rather than size, they are said to multiply by more than a hundredfold in number, in a matter of 23 days.

With broad, thick, glossy, ovate leaves, WH rise above the surface of the water as much as 3 feet in height although in some sites in Southeast Asia they are found to grow between 2 and 5 7 and 16 feet! [28] The aquatic weed colonizes still or slow-moving water bodies, such as estuarine habitats, lakes, urban areas, watercourses, and wetlands. It can tolerate seasonal variation in flow velocity as well as extreme fluctuations in water quality parameters including nutrients, pH, temperature and toxic substances.[29]

[24] *Ibid* 16.

[25] Penfound WT, Earle TT (1948) The biology of water hyacinth. Ecol Monogr 18:447–472.

[26] Sullivan, Paul R; Wood, Rod (2012). Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) seed longevity and the implications for management (PDF). 18th Australasian Weeds Conference. Melbourne.

[27] Dickinson, R. and Royer, F. (2014). Weeds of North America. University of Chicago Press. 625p.

[28] Gopal, B. (1987). Water Hyacinth (Aquatic Plant Studies 1). Elsevier, Amsterdam, 471p.

[29] *Ibid*.

2.2. Environmental impact of water hyacinth

Waterbodies colonized by WH undergo significant changes in their structure and aquatic habitat diversity, including the proliferation of disease transmitters and high fish mortality due to low concentrations of dissolved oxygen in water.[30] The dense mats of WH reduce light transmission to submerged plants and competes with other plants, often displacing wildlife forage and habitats[31], depletes oxygen in aquatic communities[32] resulting in a lack of phytoplankton[33] and an alteration of the composition of invertebrate communities[34,35], ultimately affecting fisheries biodiversity.[36] The plants create a prime habitat for mosquitos and other disease vectors causing schistosomiasis, filariasis, malaria, and encephalitis[37,38,39,40] by creating the favorable growth condition of micro-organisms around the plant roots and shoots.

In addition to altering the aquatic habitat structure and the ecological process, the free-floating movement of these aquatic invasive plant can affect the hydrological processes of the water bodies. By constructing a homogenous proliferation and modifying the aquatic functioning system WH hinder the water transport way and clog the water supply systems creating blockage of irrigation canals and reduced flood controls.

---

[30] Parsons WT, Cuthbertson EG (2001) Noxious Weeds of Australia. Collingwood: CSIRO Publishing, Melbourne, Australia.

[31] Center TD, Dray FA Jr, Jubinsky GP, Grodowitz MJ (1999) Biological control of water hyacinth under conditions of maintenance management: can herbicides and insects be integrated? Environmental Management 23: 241–256.

[32] Ultsch G (1973) Effects of water hyacinths (*Eichhornia crassipes*) on the microenvironment of aquatic communities. Archiv fur Hydrobiologie, 72: 460–473.

[33] McVea C, Boyd CE (1975) Effects of waterhyacinth cover on water chemistry, phytoplankton, and fish in ponds. Journal of Environmental Quality 4: 375–378.

[34] Hansen K, Ruby E, Thompson R (1971) Trophic relationships in the water hyacinth community. Quarterly Journal of the Florida Academy of Science 34: 107–113.

[35] 21. O'Hara J (1967) Invertebrates found in water hyacinth mats. Quarterly Journal of the Florida Academy of Science 30: 73–80.

[36] Voiland, A. (2016). Seven Things You Didn't Know About Water Hyacinth. Earth Observatory. Accessed on November 21, 2020.

[37] Coles, G.C.; Kabatereine, N.B. (June 2008). "Water hyacinth and the transmission of schistosomiasis". Transactions of the Royal Society of Tropical Medicine and Hygiene. 102 (6): 619–620.

[38] Muyodi, F. J. (2000). Microbiological analysis of the waters of lake Victoria in relation to the invasion of the water hyacinth, *Eichhornia crassipes* (Mart.) solms: a case study of the lake Shores of Mwanza Municipality, Doctoral dissertation, University of Dar es Salaam.

[39] Reddy, K. R., & DeBusk, W. F. (1991). Decomposition of water hyacinth detritus in eutrophic lake water. Hydrobiologia, 211(2), 101-109.

[40] Minakawa, N., Sonye, G., Dida, G.O. et al. (2008). Recent reduction in the water level of Lake Victoria has created more habitats for Anopheles funestus. Malar J 7, 119. https://doi.org/10.1186/1475-2875-7-119

2.3. Control of water hyacinth

Many management programs have been put in place over the past several decades throughout the world to eradicate this invasive species from the affected waterbodies. Most of the programs focussed on eradication through chemical, physical or biological means; and have had little lasting success[41]. This has been largely due to aggressive propagation capacity of the weed and viability of its seeds despite substantial monetary investments over the years[42], and partly due to lack of continued policy and management support by the governments. Applications of herbicides over large area result in large quantities of WH biomass sinking in water along with non-targeted plants resulting more severe problem.[43] Physical removal of WH can completely eliminate the plant biomass from water, however, infestation occurs again in a couple of years.[44,45] Besides, physical control has severe limitations in terms of economical and safety perspectives. Mechanical removal minimizes those limitations but limit the success as WH can grow quickly from different remaining parts.[46] Biological control also didn't bring any success to eliminate WH.[47]

2.4. WH menace: Bangladesh perspective

Bangladesh, having rich inland waters and river systems, has significant fishery and aquaculture potential because of its favourable geographic position and large number of aquatic species. The presence of WH in the inland aquaculture sector reduces oxygen in the water, makes the floor of water bodies to rise fast decreasing the volume of water bodies and causing the death of native fish that ultimately results in depletion of

[41] Wilson, J.R., Holst, N., Rees, M., (2005). Determinants and patterns of population growth in water hyacinth. Aquatic Botany, 81, 51-67.

[42] Gichuki, J., Omondi, R., Boera, P., Tom Okorut, T., SaidMatano, A., Jembe, T. and Ofulla, A., (2012). Water Hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach Dynamics and Succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications for Water Quality and Biodiversity Conservation. The Scientific World Journal, doi:10.1100/2012/106429.

[43] Woomer, P.L., R. Muzira, D. Bwamiki, D. Mutetikka, A. Amoding and M.A. Bekunda, (2000). Biological management of water hyacinth waste in Uganda. Biol. Agri. Hortic., 17: 181-196.

[44] OH Odountan, L Janssens de Bisthoven, CZ Koudenoukpo, Y Abou. (2019) Spatio-temporal variation of environmental variables and aquatic macroinvertebrate assemblages in Lake Nokoué, a RAMSAR site of Benin. African Journal of Aquatic Science 44:3, pages 219-231.

[45] UNEP, 2008. Africa Atlas of our changing environment Division of Early Warning and Assessment (DEWA). United Nations Environment Programme, Nairobi.

[46] Güereña, D., Neufeldt, H., Berazneva, J. and Duby, S., 2018. Water hyacinth control in Lake Victoria: Transforming an ecological catastrophe into economic, social, and environmental benefits. Sustainable Production and Consumption (doi.org/10.1016/j.spc.2015.06.003).

[47] Taylor, S.J., Downie, D.A. and Paterson, I.D., 2011. Genetic diversity of introduced populations of the water hyacinth biological control agent *Eccritotarsus catarinensis*. Biological Control, 58: 330-336.

fisheries biodiversity. It also makes navigation difficult and use of water becomes unsuitable for subsistence fishing activities, irrigation, bathing and other household purposes. The aquatic weed increases evapotranspirative water losses, with estimates varying from 2.67 times[48] to 3.2 times[49] more from a dense mat of WH compared to open water.

The evapotranspirative effect of WH is of particular relevance to Bangladesh because canals infested with this weed can hardly provide water for much needed irrigation during dry season. Such impacts are evident in polder areas where ground water sources are limited. As has been mentioned in Section 1.2, most of the polders have become waterlogged due to siltation in the rivers connected by sluice gates with the canals. Almost all canals particularly those situated upstream or those having lost connectivity with the rivers have become heavily infested with this obnoxious species creating havoc in terms of navigation, irrigation, sluice operation, siltation within canal beds. Besides, WH has spread over waterlogged low-lying areas which otherwise could be used for aquaculture and subsistence fishing activities while providing surface water sources for other community purposes irrigation, bathing and so on.

Apart from siltation and drying up of river beds, nutrient run-offs from agricultural farms in the polder areas also cause the massive growth of this aquatic weed over the water bodies and cause the death of an aquatic ecosystem eventually. Bangladesh is a country where excessive fertilization is a common phenomenon because of agricultural practices with high yielding varieties involving heavy reliance on the use of chemical fertilisers. The fact that the livelihoods of polder communities depend mostly on agriculture and subsistent fishing and that WH mostly affects different facets of these two livelihood activities suggest that it is the poor polder communities that suffer most from the infestation of this aquatic weed and unless eradicated appropriately the livelihoods of polder communities would be further jeopardized. As with other parts of the world, Bangladesh also experienced similar difficulties to eradicate this 'nuisance species' from the vast natural water bodies of the country, although there has been no systematic and comprehensive programme or project to that end.

[48] Lallana VH, Sabattini RA, Lallana MdC (1987). Evapotranspiration from *Eichhornia crassipes, Pistia stratiotes*, *Salvinia herzogii*, *and Azolla caroliniana* during summer in Argentina. Journal of Aquatic Plant Management 25: 48–50.

[49] Penfound WT, Earle TT (1948). The Biology of the Water Hyacinth. Ecological Monographs 18: 447–472.

3. Description of the project

3.1. Rationale

From the preceding section, it has become clear that apart from severe ecological degradation and biodiversity loss in southwest polder areas, the socio-economic and public health issues associated with proliferation of WH are of grave concern. Community involvement in water hyacinth eradication is a promising avenue to explore[50], but so far, no serious attempt has been made to test this hypothesis. As has been mentioned, past attempts to control this weed through various means did not work leaving 'the concept of eradication through utilization' as the most rationale option worth trying.

Community participation appears to hold potential for multiple benefits: it addresses the alternative livelihood issues of poor coastal community where an apparent value and thus demand for water hyacinth will provide necessary impetus for small cottage industry development while eradication of WH on a sustainable basis will provide multiple other socio-economic and environmental benefits. It was, therefore, necessary to showcase a technology that could turn this nuisance into resource through community participation. To this end, a pilot project entitled "Development of value-added products from water hyacinth to support alternative livelihoods and ecological resilience in coastal villages of southwest Bangladesh" was implemented by KU with global experience from WUR.

3.2. Goal and objectives

The overarching goal of this pilot project was to develop and promote community-based physical mean as a sustainable solution to eradicate water hyacinth from the affected water bodies while forming an alternative livelihood opportunity for the resource-poor coastal community of Bangladesh.

The project-level specific objectives were as follows:

- To showcase a business model where value-added products in the form of pulp and craft paper would be produced from water hyacinth using a simple and tested protocol;

[50] Uchida, H. and Ando, K. (1998). Water Hyacinth Control Program through Community Development Approach: A Case Study in a Bangladesh Village. JARQ, 32: 181-186.

- To use the raw water hyacinth and/or the process by-products for compost production for local use;
- To facilitate market linkage with the relevant industries, artisan shop, and others.

3.3. Approach and methodology

A participatory research and development approach was followed for this project where both laboratory optimization and filed testing were carried out involving southwest polder community members. At the outset, reconnaissance, site visits, key informant interview (KII), focus group discussions (FGD) and planning meetings were undertaken that set the stage for understanding the problems posed by uncontrolled growth and spreading of water hyacinth on the coastal community's lives and livelihoods, with particular emphasis on its resource potential and community mobilization to realize the potential. Consultation with polder community members and relevant stakeholders was an integral part during planning and implementation of project activities that enabled the project team to select appropriate site and participants, fine tune the methodology and ensure stakeholders commitments to achieve timely outputs of the project as planned. Further details on the materials and methods applied for production of craft papers and compost from WH are described in the relevant sections.

4. Project Preparations

4.1. Pilot site selection

Based on discussions with different water management groups (WMG) and BG staffs, it was decided that one of the WMGs of Polder 25 would implement project activities at Thukra, Dumuria. Located at the outskirt of Khulna City Corporation, Polder 25 comprises seven unions and two upazillas. The polder (embankment) is over 72 km in length that is connected to Hamkura River and Hari River and a number of beels[51] including Dakatia through 17 sluices (Fig. 4).

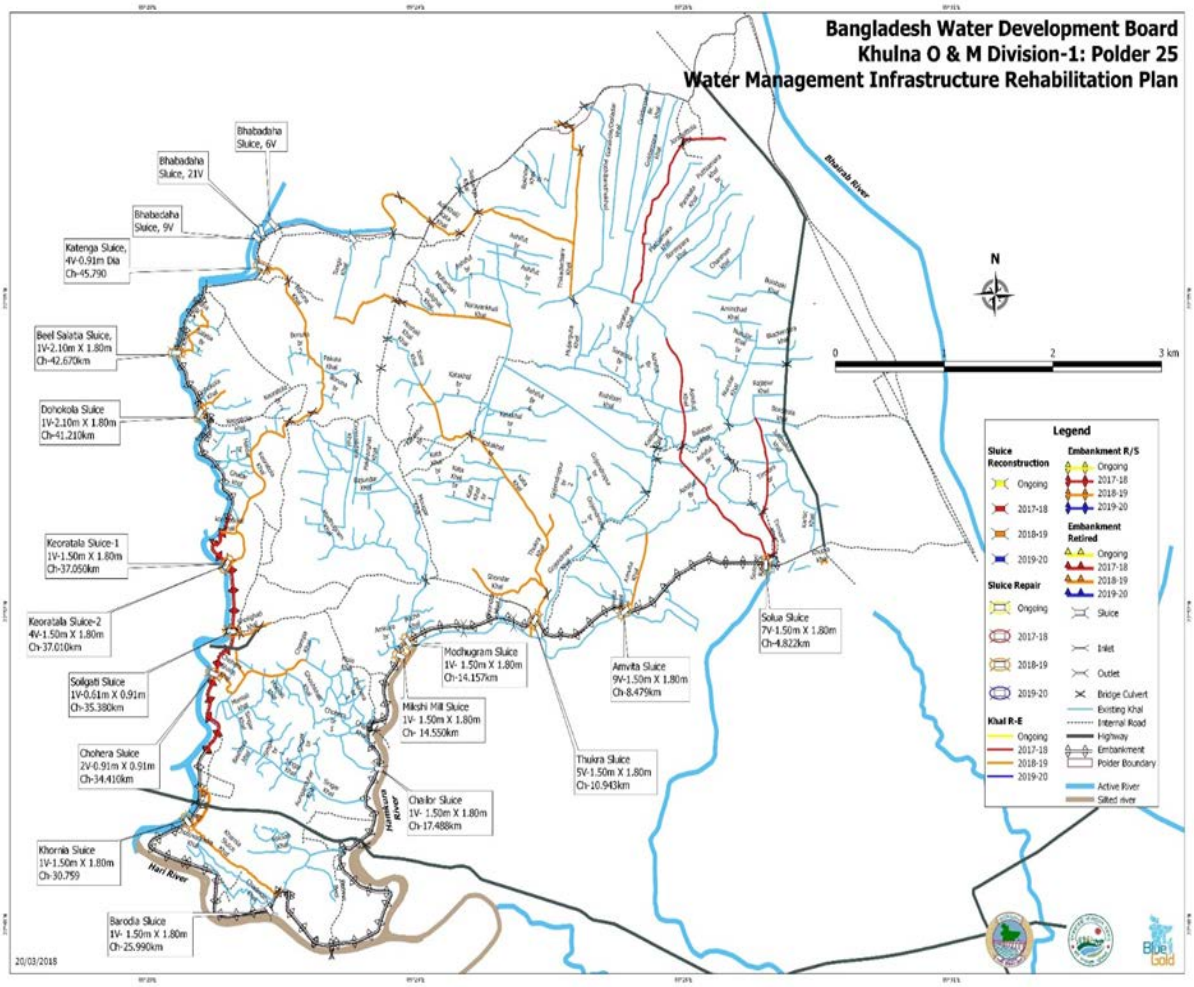

Fig. 4. Map of Polder 25 showing the location of the pilot site and other polder related information. Collected from BG with the original source mentioned on the map.

[51] Common in the GBM delta, beel is a lake-like wetland with static water. Typically, it is formed by inundation of low-lying lands during flooding, where some water gets trapped even after flood waters recede back from the flood plains.

The polder has 61 community-based WMGs comprising 8,596 male and 8,274 female members[52]. The pilot site was located by the side of Thukra canal which connects Dakatia beel to Humkura River. As with almost all natural water bodies in this polder WH is abundant throughout the Thukra canal (Fig. 5).

Fig. 5. Stakeholders consultation for site selection in Polder 25 (Thukra, Dumuria, Khulna)

4.2. Planning and inception

An inception workshop of this project was held on 19th March 2019 to share and discuss the project concepts and ideas and to ensure cooperation from the stakeholders for the successful implementation of the project. Participants were mostly comprised of WMG and WMA members from the pilot site as well as from other nearby polders while representatives from other government and non-government organisations also attended (Fig. 6). Following presentations by experts from KU and WUR on the project rationale and work plan, the participants were asked to provide their insights and opinions to finalize the management structure of the project, review the work plan, adjust and work-out operational details with possible future direction of this project.

[52] Map and data on polder 25 were collected from BG Khulna Office. Original source is mentioned in the map.

The Inception Workshop garnered high interest among the participants particularly with regard to the innovative idea of generating incomes from this otherwise nuisance species. This brainstorming session brought people together into a dynamic and lively discussion that resulted in creative thoughts and ideas throughout the session. Some of the intriguing questions and ideas that were shared and discussed included:

- What are the strengths that the project would be sustainable?

Involvement of the local people especially women, sense of ownership in WH business enterprise, proximity of Khulna University as a knowledge generation and technology dissemination institute, plenty of raw materials supply and simple production technology would ensure its sustainability.

- What would be the market of the WH-based products?

It is possible to sell the products at both and domestic and international markets provided the linkages are established during the project tenure. Thus, an integral part of the pilot project should be making a good business plan for the domestic and international markets where the development partners can work. Representatives from NGOs showed keen interest in the development of such business proposition in their respective working fields because this has the potential of providing alternative livelihood opportunities for the resource poor climatically stressed coastal people. Some of the participants acknowledged that they never thought water hyacinth could offer such income generating activities and they expressed their interest to follow the piloting activities.

Fig. 6. Participants from KU, WUR, BG, WMG of Polder 25 and other stakeholders at the Inception Workshop

Some of the intriguing and specific suggestions and ideas that came out from the discussion included chemical analysis of the water hyacinth products specially for heavy metals; advertising organic fertilizers made from water hyacinth; establishment of a showroom for the water hyacinth products; promoting craft papers among the visitors to the Sundarbans; organizing an art competition to promote nature based products using nature inspired themes and branding of environmental friendly water hyacinth products among corporate bodies. Thus, the workshop was highly successful in ensuring commitment from those who would actively participate in project activities while others provided valuable insights into future business aspect of this innovative project.

4.3. Business model development

Undoubtedly, sustainability of any community driven enterprises depends on establishing a viable and sustainable market linkage and this is more so for such unconventional products as WH based craft papers, which have very niche market. This issue has been raised on many occasions during Inception Workshop and in consultation meetings with community and various stakeholders including the BGIF team. It was decided that in parallel to piloting activities, a Market Feasibility Study of WH-based craft papers should be carried out and an addendum in contract has been signed to this effect. Accordingly, we carried out the market study to understand how community members can be linked to existing and new markets, what would be the business model, how value addition can be done, and how this business model can be made viable and sustainable while setting up the pilot facility with the help of WMG in Thukra, Dumuria.

Fig. 7. Participants at the business development workshop held in Khulna

The project team arranged a consultation meeting with a variety of stakeholders including BGIF team, WMG members, local entrepreneurs, representative of divisional corporate organizations, art teacher, successful entrepreneurs of Khulna, related local business representatives to discuss the commercial feasibility and to identify possible entry points for the domestic market (Fig. 7). A detailed report on the findings of the market feasibility study had earlier been submitted to BGIF[53].

The project team also started communicating with potential partners to realize the business potential considering that the pilot production of WH based products would be successful. To this end, several meetings were conducted with organizations known for working with coastal community for income generating activities. At about the same time the PI communicated with another organization 'Prokritee', known for its pioneering community-led handcraft business with strong international market linkage. The visit to 'Biborton' project of Prokritee in Agailjhara, Barisal provided further insights into pulp production technology that KU research team had already developed, particularly with regard to fabricating the machineries to suit local conditions. The visit ensured follow-up exposure visit by WMG representatives (Fig. 8) and a commitment from Prokritee management regarding market linkage of WH-based craft papers.

Fig. 8. Exposure visit to Biborton project of 'Prokritee' in Agailjhara, Barisal to observe handmade paper and paper crafts production from water hyacinth

[53] Ahsan, MN, Nabi, MNU and Islam MN (2019). Analysis of Commercial Feasibility of the Water Hyacinth (WH) Paper in the Domestic Market of Bangladesh, Blue Gold Program, Bangladesh, 65p.

5. Product Development Process Optimization

This was one of the important activities of this pilot project that entailed optimization of laboratory prototype to suit community-based production system for the production of craft paper and compost from WH. As shown in the schematic diagram (Fig. 9), the pilot project had two components: production of pulp for craft paper as the main component while production of compost using process by-products as an added component.

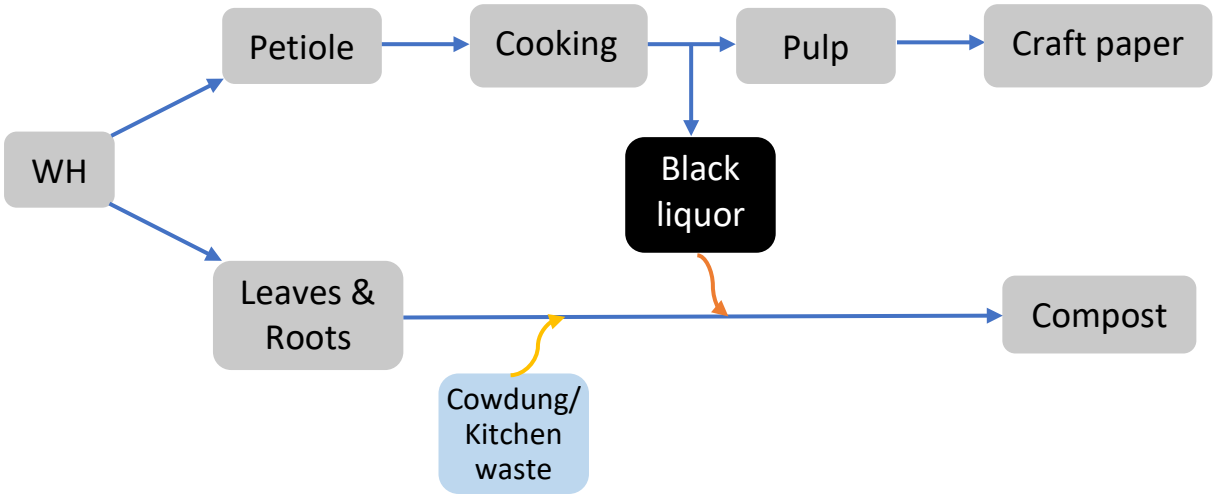

Fig. 9. Schematic diagram showing the production process of craft paper and compost from water hyacinth

WH petioles (stalks) were cooked with caustic soda to produce pulp and craft paper while the liquid portion rich in potassium was used in preparation of compost with left over leaves and roots of WH. In practice, production parameters for both pulp and compost were optimized at laboratory condition while preparing for pilot set up and then the pilot run was carried out with the optimum parameters determined at the laboratory trials. The laboratory protocols and the results obtained are briefly described in the following sections[54].

5.1. Process optimization for craft paper

After removing the leaves and roots, the petioles (stalks) of WH were dried, chopped into small pieces and cooked for two hours with potassium hydroxide (KOH), known as

[54] A manuscript containing further technical details have been submitted for publication in a peer-reviewed scientific journal with due acknowledgement to BGIF.

caustic soda. The cooking process was optimized so that individual fibers are separated from each other with the minimum degree of physical damage to the fibers while chemical treatment was performed to the extent that the maximum amount of lignin from the fibers to obtain pulp of desired quality (Fig. 10). It was found that 10% alkali treatment resulted in the highest amount of pulp from WH (31.9% of dry weight WH) under the experimental condition as summarized in Table 1.

Fig 10. Pulp produced from fresh water hyacinth stalks

The resulting pulp was washed with tap water to remove residual cooking liquor and remove oversized particles so that the pulp becomes suitable for paper production. The liquid portion known as black liquor was used for compost production (described later).

Table 1. Cooking and bleaching conditions

Cooking		Bleaching	
Raw material (gm) (oven dried)	400	Consistency	20%
Active alkali	8-12%	pH	10
Liquor to chips ratio	9:1	Temperature	80 ºC
Temperature	125 ºC	Time	90 min
Time	130 min	Washing (tap water)	4-5 times

Pulp obtained after washing can be used directly for paper production. However, at this stage it remains too dark to be used for many paper products and therefore bleaching is often necessary. Bleaching is done to increase the brightness of pulp so that it can be used in paper products such as printing grade papers and tissue papers. In this study, unbleached pulp was mixed with hydrogen peroxide (H_2O_2) or Calcium hypochlorite ($CaO(Cl)_2$) at a ratio of 4:1, kept in a warm condition for 90 min and then washed with tap water to obtain bleached pulp of light color (Fig. 11).

Fig. 11. Unbleached (left) and bleached pulp (right) made from water hyacinth

Hand sheet was made from both unbleached and bleached pulp with a shit thickness of 80 GSM (gram square meter) using a hand sheet making machine having a diameter of 22 cm. The wet hand sheets were dried in a paper drier machine at 100^0C for 5-6 min. After drying, calendaring was done manually to obtain smooth surface (Fig. 12). Refer to Table 1 for the cooking and bleaching conditions used for pulp production from WH.

Fig. 12. Handmade paper made from bleached (light) and unbleached pulp (dark)

Finally, the hand sheets thus prepared were subjected to assessment of various properties including brightness, tensile index and tear index. Brightness is measured as the amount of light reflected from the surface of a paper while tensile and tear indices indicate the lignin and cellulose contents and the extent of hydrogen bonding among adjacent fibers. Brightness, tensile index and tear index of hand sheets following bleaching were found to be high suggesting significant contribution of bleaching on WH paper quality (Table 2).

Table 2. Quality indices of handmade paper before and after bleaching

Quality indices	Pulp	
	Unbleached	Bleached
Brightness (ISO %)	10.6	36.78
Tensile index (Nm/g)	41.69	48.94
Tear index (mN m^2/g)	3.27	7.68

The result showed that, apart from brightness bleaching with H_2O_2 or $CaO(Cl)_2$ also increased the tear index significantly suggesting better removal of lignin and exposure of cellulose that in turn resulted in formation of more hydrogen bonds between adjacent fibers.

5.2. Process optimization for compost

The effect of black liquor on compost quality was tested under laboratory condition using plastic composting bins. As shown in Table 3, three types of composts were tested for this experiment: WH only (left over roots, leaves from the pulping process) (WH-O); WH mixed with cow dung at a ratio of 5:2 (WH-C) and WH mixed with black liquor (process by-product from the pulping process) at a ratio of 3:1 (WH-B). The compost bins were covered with occasional mixing of the materials and with occasional addition of water to keep moisture content at around 60% and the composting process were allowed to take place for 90 days.

Table 3. Compost types and composition

Compost type	Composting materials		
	Water hyacinth (Kg)	Cow dung (Kg)	Black liquor (L)
WH only (WH-O)	15	-	-
WH with cow dung (WH-C)	10.5	4.5	-
WH with black liquor (WH-B)	11.25	-	3.75

The three final compost products were analyzed for the following parameters: pH, water soluble carbon, ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (N), total phosphorus (P), and total potassium (K) and the results are presented in Table 4. There was a higher increase in P and nitrate-N in WH-C and WH-B composts than in WH-O compost. WH-C compost had higher increase in Ammonium-N than in WH-B and WH-O composts.

Table 4. Values of quality parameters of three types of WH-based compost

Quality parametrs	Compost type		
	WH with cow dung (WH-C)	**WH with black liquor (WH-B)**	**WH only (WH-O)**
Total Kjeldahl nitrogen (%)	1.12 ± 0.13	1.14 ± 0.09	1.07 ± 0.05
Total phosphorus (mg/Kg)	3.11 ± 0.26	3.19 ± 0.34	2.68 ± 0.16
Total potassium (mg/Kg)	12.51 ± 3.26	13.30 ± 3.38	12.44 ± 3.57
NH_4-N (mg/Kg)	3.83 ± 3.01	3.81 ± 3.02	3.68 ± 1.27
NO_3-N (mg/Kg)	43.10 ± 20.26	44.48 ± 40.22	38.93 ± 19.55
Water soluble carbon (gm/Kg)	0.12 ± 0.06	0.13 ± 0.10	0.11 ± 0.08
pH	7.90 ± 0.22	7.78 ± 0.36	8.70 ± 0.14

Overall, based on the levels of N and K WH-C and WH-B produced composts of similar quality but when the P value was considered WH-B appeared to better with an alkaline pH from 7.78 to 8.70. Since, KOH was used during pulping process the black liquor naturally contained large amount of potassium, that increased the level of this important element in the final compost.

It should be mentioned that we also performed another set of experiment replacing cow dung with kitchen waste and found that if black liquor was applied compost made with WH and kitchen waste produced the best quality compost in terms of high TKN, TP, TK, and pH values[55]. The optimization of potash pulping process and utilization of BL as a process by product clearly suggest its efficacy as an additional income generating opportunities for the WH-based cottage industry and the community members were invited to learn and experience the composting process (Fig. 13).

Fig. 13. Compost production before (top left) and after (bottom left) 90 days and demonstration to community members (right)

[55] A manuscript containing further technical details have been submitted for publication in a peer-reviewed scientific journal with due acknowledgement to BGIF.

6. Pilot Production of WH-based Products

Development of value-added products from WH through community participation in the field was at the core and the most substantial activity of this pilot project. Preparations for the pilot site was started right from the beginning of the project and while the laboratory process optimization had been going on, we tried to fabricate machines essential for pulp production. The principal of machine fabrication was that the parts and materials should be cheap, simple and be locally available. A series of consultations meetings with the WMG members and small engineering shops enabled us to finalize the layout and design specification of each machine. We also performed minor civil, plumbing and electric provisions in the room of the pilot site pilot site as the production process required and to accommodate for the machines (Fig. 14).

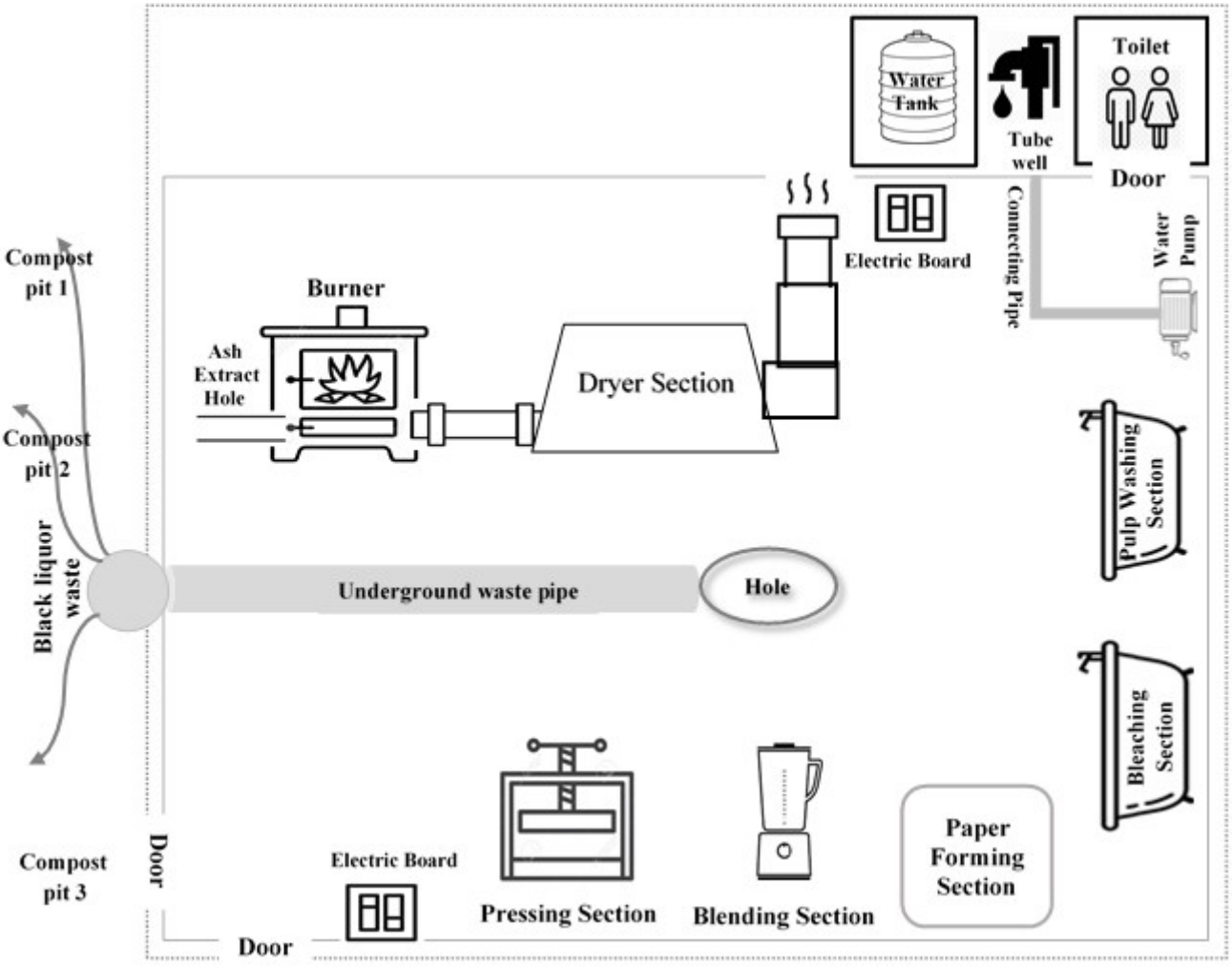

Fig. 14. Layout of the pilot production site showing position and orientation of equipments necessary for craft paper and compost production from water hyacinth

6.1. Pilot production of craft paper

The production process was similar to that described for laboratory optimization except change in machineries and the volumes used. The production process as followed in the pilot set up are briefly described below:

Raw materials collection and processing

Fresh and mature WH was collected from the Thukra canal flowing nearby. Potassium hydroxide (KOH), known as caustic soda, and Calcium hypochlorite ($CaO(Cl)_2$), known as bleaching powder were procured from the local market. After removing the leaves and roots, the petioles were air dried for 3 days and cut into small pieces of about 3 cm in length (Fig. 15-1).

Fig. 15-1. Processing of water hyacinth petiole for cooking

Cooking of water hyacinth stalks

The air-dried pieces of petioles were cooked in an aluminum pan with water and potassium hydroxide until the petiole became soft, which was approximately 3 hours (Fig. 15-2). Twenty-gram potassium hydroxide and 500 mL of water were added with 100 g air dried WH stacks.

Fig. 15-2. Cooking of water hyacinth stalks with water and potassium hydroxide

Pulp washing and disintegration

After cooking, the semi solid pulp was separated from the liquid known as black liquor (BL). For this, pulp was washed with tube well water for 4-5 times. Later, a locally fabricated blender was used to disintegrate the pulp and remove the uncooked stalks of WH (Fig. 15-3).

Fig. 15-3. Disintegration of pulp using a blender

Bleaching of pulp

The disintegrated pulp was then bleached by a single stage bleaching using bleaching powder. 10 g bleaching powder and 200 mL water were added with 100 g disintegrated pulp materials. The temperature of the mixture was maintained at around 80 ^{0}C for 90 min. In practice, leaving the pan with its lid closed on the brick-made stove without flame was sufficient to maintain similar temperature. After bleaching, the pulp materials were washed with tube well water (Fig. 15-4).

Fig. 15-4. Washing of pulp after bleaching

Hand sheet making

Hand sheet was made from both unbleached and bleached pulps. Before making hand sheet, pulp was again disintegrated using the blender. To obtain 80 GSM paper, 100 g pulp was mixed with 20 L of water in a bucket. After proper mixing, a screen mold was placed in the bucket and pulp slurry was drawn. Water was allowed to drain out of the screen leaving the thick slurry on the screen (15-5). Subsequently, a cheese cloth was placed over the slurry so that the slurry can be peeled off from the screen. GSM of paper can be changed by increasing/decreasing the amount of pulp.

Fig. 15-5. Washing of pulp after bleaching

Drying and calendaring of hand sheet

Several pieces of cheese cloths containing the wet hand sheets from the previous step were piled and pressed to remove excess water. The semi moist hand sheet containing cheese cloths were then dried by hanging them over the hot smoke vent or outside in the sun. After drying, dry hand sheets were peeled off from the chesse cloths and calendaring was done manually to obtain smooth paper surface, which can be used to produce paper crafts (Fig. 15-6).

Fig. 15-6. Final hand sheet from water hyacinth

6.2. Pilot production of compost

Trained polder community members prepared three earthen three earthen pits beside the craft paper facility for making compost using WH leaves and roots that were not used for pulping process. The WMG members produced compost using a mixture of WH, cow dung and black liquor as this combination produced the best compost in the laboratory trial with plastic drum.

Fig. 16. Compost production scheme (left) and compost pit at the pilot site (right)

7. Capacity Development

Arranging and facilitating a series of consultation meetings, KIIs, FGDs, workshops and trainings on development of value-added products from WH formed an integral part of this pilot project. All trainings were hands on in nature where the participants were allowed to perform each step by them under the supervision of experts. Apart from PI, Co-PIs and other project team members, experts from different organizations facilitated the training programs. The topics covered both craft paper and compost production with participants drawn from the WMG comprising both male and female members of the polder community.

7.1. Trainings on craft papers and compost production from WH

A total of six batches of trainings were conducted on craft paper in the lab and compost at KU premise while another set of trainings were conducted at the pilot site where participants had another refresher training followed by sessions that allowed them to practise their knowledge gained from previous trainings (Fig. 17; Table 5).

Fig. 17. WMG members in hands-on training conducted at KU lab (left) and at pilot site (right)

Table 5. List trainings conducted on craft papers and compost production from WH

Sl.	Date	Training Topic	Venue	Total Trainees	Male	Female
1	04 Oct, 2019; Friday	Craft paper production from Water hyacinth (Batch-01)	Khulna University	10	4	6
2	05 Oct, 2019; Saturday	Compost production from Water hyacinth (Batch-01)		11	5	6
3	09 Oct, 2019; Wednesday	Craft paper production from Water Hyacinth (Batch-02)		10	5	5
4	10 Oct, 2019; Thursday	Compost production from Water hyacinth (Batch-02)		10	5	5
5	11 Oct, 2019; Friday	Craft paper production from Water hyacinth (Batch-03)		10	5	5
6	12 Oct, 2019; Saturday	Compost production from Water hyacinth (Batch-03)		10	5	5
7	23 Nov, 2019; Saturday	Craft paper production from Water hyacinth	Polder 25 (Thukra bazar)	16	7	9
8	24 Nov, 2019; Sunday	Compost production from Water hyacinth		16	7	9

All of these trainings and piloting activities described in the preceding sections resulted in capacity building of WMG of Polder 25 who successfully produced craft papers and compost from WH while a parallel study analysed value chain mapping and market feasibility of WH-based craft papers in the domestic market of Bangladesh.

7.2. Market development and consumer networking trainings

Building on the momentum created another addendum to the existing contract was made to undertake additional activities focusing on awareness building among specific consumers, capacity building of the community and penetration into existing market for WH based products. The activities included skills training, consumer showcasing and art competition, all involving WH-based craft papers produced by the polder community.

7.2.1. Skills development training

The list of market development trainings conducted is summarized in Table 6 with a brief description of each in the following paragraphs:

Table 6. List of trainings conducted for market promotion of WH-based products

Sl.	Date	Training Topic	Venue	Total Trainees	Male	Female
1.	23 Aug, 2020; Sunday	Capacity building training on value addition to WH craft papers	Polder 25 (Thukra bazar)	12	5	7
2.	24 Aug, 2020; Monday	Capacity building training on craft making		12	5	7
	25 Aug, 2020; Tuesday			13	5	8
3.	27 Sept, 2020; Sunday	Capacity building training on niche marketing of eco products		11	4	7

❖ *Capacity building training on value addition to WH craft papers*

Members of WMG under Polder 25 had already been trained on how to produce good quality pulp from WH, bleaching of pulp and craft paper making. However, they lacked the know-how on producing different kinds of high value craft paper. The market feasibility study had revealed that economic sustainability of the craft paper producers would depend on the capability of the producers to diversify their products portfolio such as color paper, tissue paper, warping paper, sack paper, paper board and so on using WH. With the help of relevant experts in the field, we arranged one-day hands-on training for the community members at the piloting site.

❖ *Capacity building training on craft making*

Market feasibility study also revealed that apart from the craft papers, there was substantial growth potential for crafts produced by the craft papers. Only craft paper production capability of the farmers of WMG under Polder 25 would not help in the long run. Community members

lacked that specific craftsmanship. To address this capacity development issue, we conducted a two-day training program with various sessions to demonstrate how to produce different crafts such as ornament box, tissue box, note book, flower vase, photo frame from WH craft papers made by themselves.

❖ *Capacity building training on niche marketing of eco-products*

Commercial success of WH and other craft paper and paper products depend on the successful niche marketing. A basic market identification, product planning, market segmentation, and market communication training was delivered to the members of WMG who took part in the piloting activities in Polder 25. Participants who took part in the earlier product diversification and crafts making training took part in this training conducted at the piloting premise.

7.2.2. Showcasing and merchandizing of WH paper products

A consumer pooling strategy is essential in order to popularize a product in the market, which is uncommon such craft papers made from WH by the coastal community. From the market feasibility study, we learned that consumers were not aware at all of existence of such products in the market, although some knew it through media reports. In this activity, we approached a local shop owner who sells artisan materials and persuaded him to dedicate a space in his shop[56] so that the WH-based craft papers and crafts produced by the polder community can be displayed and sold to potential users (Fig. 18).

Fig. 18. Showcase in a craft shop dedicated for WH products produced by WMG

[56] *Nagordola*, Islamnagar road (bypass link road), Khulna 9208.

Although insignificant in terms of customer base one could expect a single shop can cover, it would certainly help to draw the attention of some potential consumers at the point-of-sale.

7.3. Organizing art competition

Organizing an art competition was an innovative campaign idea by the project team to draw attention of a large population in a short period of time. It was planned that a drawing and painting competition entitled “Colors of Nature” would be arranged where students of the Drawing and Painting Discipline, Fine Arts School of Khulna University and the Water Color Painter Group of Khulna would use WH craft papers made by the polder community. It was hoped that due to its innovativeness and festive mode at least 100 distinguished audiences will be visiting the competition and exhibition venue that would be open for visitors.

However, due to Covid 19 pandemic situation that prohibited public gathering and discouraged long distance transport and that kept the university closed during this time, the project team in consultation with KU authority and the BGIF authority decided to conduct the coemption virtually (Fig. 19).

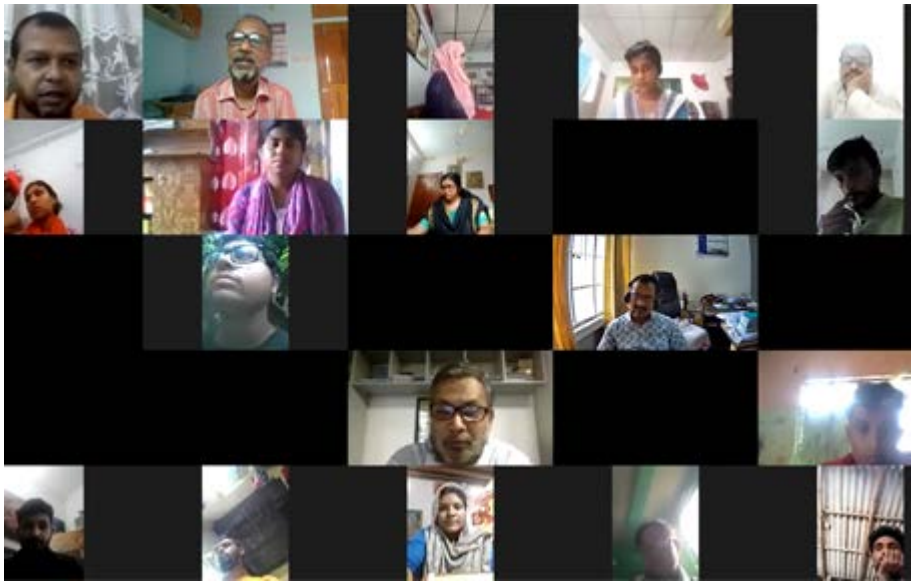

Fig. 19. Screenshot of participants in virtual Art Competition, Colors of Nature

As with the theme of the art competition (i.e., painting with WH paper produced by polder community) arranging a virtual art competition without compromising that very theme was in itself an innovative idea as well. Candidates registered on-line received WH paper and other materials through courier and they were asked to take part in the art competition from their home while being connected through online application, Zoom. On 4 October, 2020 the Vice Chancellor of Khulna University inaugurated the art competition while a host of other distinguished guests including representative from BG Dhaka office joined virtually. A panel of independent judges selected top five from the 32 participants who could manage to join and who sent digital copies of their art works within the stipulated time (Fig 20).

Fig. 20. Judges selecting the best works from WH Art Competition

7.4. Project completion workshop

A project completion meeting and prize giving ceremony was held on 17 November, 2020 at Khulna University Life Science School Meeting Room with physical presence of a limited number of participants from the university and the polder community while representatives from BG other stakeholders joined virtually. Following a brief presentation on the activities performed and outputs achieved a video documentary prepared by the project team was shared, which was highly applauded by the workshop participants. As a side event, the top finalists of the art competition held previously were declared by the hon'ble Vice Chancellor of Khulna University, which was followed by prize giving and speeches by representatives from various stakeholders including polder community and the Team Leader of Blue Gold Program Bangladesh (Fig. 21).

Fig. 21. Participants present both physically and virtually at the final workshop (left) and a group photo of the best artists of the Art Competition

The participants in the final meeting expressed their gratitude to BG for funding this project and KU for undertaking this innovative research project with the polder community. It was hoped that with the knowledge and expertise gained the polder community members would be able to sustainably produce craft paper and compost from WH and would be self-reliant on their own. Since apart from specific skills development of such value-added products does not need much infrastructure, community in and around other polder areas in the southwest coastal districts would be able to take advantage of the technology to make a living while making natural waterbodies more productive through eradicating WH.

8. Summary and Conclusion

Water Hyacinth is globally referred to as a 'menace' as it clogs the canal water flow, creates barrier in the water flow at the intersection between river and canal, decreases the breeding of fish and makes water unsuitable for various productive use by rural community people. Various efforts to control its spread have been taken up in many countries that include physical, mechanical, biological, or chemical means with, however, little success. Past research conducted by KU, a leading public university in the divisional headquarter of southwest Bangladesh, in collaboration with WUR, a university in the Netherlands of international repute has developed the prototypes for development of value added products from WH and successfully piloted that with members of WMG under Polder 25 in Thukra, Dumuria, Khulna.

At the outset, reconnaissance, site visits, focus group discussions and planning meetings were undertaken that set the stage for understanding the problems posed by uncontrolled growth and spreading of water hyacinth on the coastal community's lives and livelihoods, with particular emphasis on its resource potential and community mobilization to realize the potential. The pilot project had two components with production of pulp for craft paper as the main component while production of compost using process by-products as an added component. The leaves and roots of the collected fresh water hyacinth was removed and the petiole was chipped and air dried. The plant materials were then cooked using KOH for producing pulp while bleaching powder was used to make the pulp white and bright. Finally, the handmade craft paper was produced from the both bleached and unbleached pulps using the locally fabricated machineries. On the other hand, the collected black liquor was mixed with the water hyacinth leaves, roots and whole fresh one to make compost rich in potassium and other macro nutrients.

After optimizing the process condition, it was found that the highest yield was obtained at around 33% when the alkali charge and cooking time were 10% and 2 hours, respectively. The brightness, tear and tensile indices of WH craft papers were also found to be within acceptable limits. The WMG members successfully produced hand sheet of different qualities using the locally fabricated machineries. Meanwhile, compost produced with water hyacinth supplemented with cow dung appeared to be best in terms of various physicochemical parameters of the compost. The unused leaves and roots of WH are naturally rich in nitrogen but inclusion of pulp process waste, called black liquor, also contributed to increased potassium content of the final compost as potassium hydroxide was used for digestion of raw WH stems.

The prototype we developed and handed over to one of the WMGs under Polder 25 does not require any costly equipment and chemicals, which means this technology can easily be adapted at wider polder community level. The pilot project successfully demonstrated on-site pulp production from WH through a participatory approach, produced craft paper from the pulp using simple hand held pressing machines by community members, utilized the by-products for compost production in combination with other locally available agricultural wastes and identified some avenues for market linkage. Through market feasibility study, a 'Business Model Canvas' was developed by identifying the necessary business processes, cost structure, revenue streams and key activities for successful entry into existing and new markets. The market feasibility study also identified challenges that could possibly be faced by the polder community including competition from established business houses who rely on handmade paper imported from overseas countries. Diversification of products made from WH craft papers and keeping price competitiveness remain major challenges for sustainable marketing necessary for community entrepreneurship development in WH business piloted and described in this report.

The most critical aspect of success in developing value added products from WH in this study was community participation, hands-on training on product diversification that requires specific craftsmanship and that requires time and patience to be achieved. Another critical aspect was fabrication of machineries using locally available materials through local light engineering workshops so as to keep the investment cost to its minimum. Further studies on the design, specifications and life cycles of individual machines should be carried out so that the equipments are durable and efficient while being cost-effective.

The on-site pulp and compost production techniques will negate the necessity of unsustainable chemical or impractical mechanical cleaning of WH for off-site dumping which often contaminates new water bodies. Apart from being environment friendly, the ingenuity of this model lies within the fact that it addresses the alternative livelihood issues of poor coastal community where an apparent value and thus demand for WH will provide necessary impetus for small cottage industry development while eradication of WH on a sustainable basis will provide multiple other socio-economic and environmental benefits.

Issues that, in the view of the investigators, still need to be addressed to ensure sustainability are pointed out in the following section.

9. Recommendations

Infestation with WH is a symptom of larger waterfront management and pollution issues. This calls for national and transboundary robust management strategies and action plans regarding the complexity of control options and the potential for climate change to help spread water hyacinth. A multidisciplinary strategy should be designed to ensure that the aquatic weed's invasive nature and its inevitable toll on the environment are clearly understood by the highest political and administrative levels. Plans should also clearly state the role of each departments of government, stakeholders, local government institutes and local communities involved in water management issues. In order to mobilize polder communities towards eradication through utilization, awareness among local communities and all stakeholders about the environmental consequences of water hyacinth infestation and resource potential need to be created on a sustainable basis.

Piloting in more areas of the fundamental idea behind this pilot project, i.e. 'a curse can be turned into resource to result in some tangible economic, social and environmental positivity', is expected to bring a huge and real change in the psyche of the people living in the actual condition in the coastal areas in the south-western region of Bangladesh and in the similar conditions elsewhere. Such psychological change will tempt people living in the similar conditions to think outside the box with an ultimate intention to be entrepreneur based on their own resources.

It should be noted that owing to its very biological nature complete eradication of WH cannot be expected from public water bodies, unless the up and out scaling potential of WH-based products, that the present pilot has successfully demonstrated, are fully realized. Considering this scenario, mass and continuous pulling out of WH from the established environment in the long-run might emerge as a matter of concern. A mass balancing study currently implemented by WUR in Kenya might be of relevance in this regard. The other issue is, if WH craft paper and fertilizer receive a mass market acceptance, natural supply chain of WH may stand insufficient. Increased demand of WH as a raw material might create unhealthy competition among community members affecting its common resource pool attribute in one hand but, on the other hand, this might encourage the commercial farming of WH opening a new avenue of income generating activities for the resource poor coastal communities. This futuristic scenario calls for an interesting research question as to how and to what extent this might impact the customary livelihoods, ecosystem and aquaculture. Research should also be carried

out to understand how future land use and land cover changes in the dynamic delta under the climate change regime will affect the proliferation and propagation of WH in natural waterbodies of southwest coastal Bangladesh.

It should be kept in mind that unlike product development, prototype testing and piloting to adapt to field condition marketing of such products require more systematic preaching and monitoring but, most importantly, changes in customary attitudes of the consumers and those staying at the top of the pyramid who have the resources to bring about the necessary changes in policies that promote social responsibility and environmental sustainability through undertaking relevant programs and policies. Changes take a long time and results can generally not be rushed. Applying a participatory and partnership approach requires time and patience and this has to be accepted for good results to be achieved. A few months of piloting activities involving only one WMG may not be sufficient to optimise the impact of project results, to ensure sustainability and to realize the scale up and scale out potential of this business model.

As a final note, continuity is of paramount importance. The risk for relapse will increase with the duration of a break between phases. Since BG will not be rolled on to another phase, Mot Macdonald should consider utilizing its professional competence to convince and give confidence to other donors for supporting similar projects for sustaining the momentum achieved, particularly with regard to demand creation of WH based eco products.