Multiple-use of water in Bangladesh floodplains: seasonal aquaculture and conjunctive use of surface and groundwater for improved rice-fish production systems

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Abstract

This study, supported by the Challenge Program Water and Food (CPWF), aims to improve rice-fish production systems through the multiple-use of water and seasonal aquaculture interventions in Bangladesh floodplains. The study[1] focuses on community-based fish culture[2] initiatives, increasingly adopted in the agroecological zones of the major floodplains of the Padma, Testa, and Brahmaputra rivers. We use the productivity of water and fish as an indicator and hypothesize that seasonal aquaculture supported by the management of floodplains for multiple-use of water can significantly increase the productivity of rice-fish systems. Recognizing the need for innovative ways to manage human-dominated landscapes such as floodplains, we have analyzed seasonal aquaculture interventions along with local adaptation of water management strategies, including the consideration of groundwater mechanisms.

The results, supported by quantitative analysis and qualitative arguments, demonstrate the significant contribution of seasonal aquaculture in improving the rice-fish production systems of the selected floodplain sites. This was achieved through the increased productivity of water and fish and the reduction of the risk posed by arsenic contamination. We highlight the value of multiple resource use approaches to enhance the social and ecological resilience of floodplain wetlands, and the need to re-consider agricultural water management options to recognize the water requirements of other sources of food such as fish produced by capture fisheries and aquaculture.

Keywords: seasonal floodplain, aquaculture, ground water, Bangladesh, multiple water use

Running Title: Seasonal Floodplain aquaculture and groundwater management

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[1]The WorldFish Center with its national partners started this five year interdisciplinary action research project in 2005 with support from the CGIAR's Challenge Program on Water and Food (CPWF-www.**water**for**food**.org)-CP35. Initiated in five countries viz., Cambodia, Vietnam, Bangladesh, China, Mali with a broader objective to contribute towards overall floodplain management and multiple water use; the process started in 24 sites in different regions. The present study presents an overview in Bangladesh revolving around the objective of integrated resources management and multiple water use.

[2] 'Fish culture' refers to fish production combined from capture and culture fisheries (aquaculture). The term is applied f to seasonal floodplains that in the wet season are conventionally exploited for capture fisheries,. The project intervention complemented this by stocking fish, thereby augmenting natural recruitment and enhancing the fish production of the system.

Introduction

The floodplains of the world's major river systems support the livelihoods of millions (King, 2008). Seasonal floodplains retain water for 5-6 months, largely during the wet and post-wet seasons (WorldFish, 2002), often serving as private property for rice production during the dry months and as a common resource pool for catching and farming fish and other aquatic organisms while flooded or inundated (Baran et al. 2001; Sheriff et al, 2008). Floodplain ecosystems account for millions of hectares of rice land in South and South East Asia (Dey and Prein, 2004). Due to its geomorphology and the prevailing hydrological regime, Bangladesh is susceptible to annual flooding, the pattern and magnitude of inundation varing annually (Hossain, 2003). With an area of 144,000 sq km (1.44 x10^7 hectare) and a population of more than 140 million, the productive use of 3.0 million hectare of floodplains in Bangladesh adds substantively to food availability and livelihood security of the poor and marginalized (Ahmed and Luong-Van, 2009). However water allocation to fish production is highly sensitive to spatial and temporal patterns by competing users, especially irrigation and hydropower (Naiman and Bilby, 2001).

With critical challenges in water resource management faced by the developing world (Tyler and Fajber, 2009), the need to promote multiple-use of water resources (Meinzen-Dick and Bakker, 2000, Van Koppen et al., 2008) and enhance water productivity (Molden et al., 2007) have gained significant influence. Water productivity (WP) has been defined as'*…the ratio of net benefits from crops, forestry, fishery, livestock and mixed agriculture systems to the amount to water required to produce those benefits'* (Molden et al. 2007). Fisheries and aquaculture (lumped together as fish production) were considered as '*non-depletive*[1] *water use systems'* that potentially complement crop production and increase overall water productivity (Molden, 1997). Yet aquaculture production has often been described as a water intensive activity (Jensen, 1989, Phillips et al., 1991) and a significant consumer of both ground and surface water (Reddy et al., 1996; FAO, 2007; Putheti, et al., 2008). Table 1 illustrates the proportion and comparative water use attributed to aquaculture and agriculture water use in different categories of floodplains.

Because of the multi-scale and multi-temporal complexity of determining qualitative and quantitative water requirements to support fisheries and aquaculture, the water productivity framework with its inherent focus on crops needed considerable further development in order to include other agricultural outputs such as livestock and fish. Drawing from Molden et al. (2007) and Peden et al. (2007), Nguyen Khoa et al. (2008) revised the concept and analyzed its application in fisheries and aquaculture. They defined water productivity in fisheries and aquaculture as '*the ratio of net beneficial fish related products and services to the volume of water in which they are produced'*. The authors concluded that to usefully apply the concept requires a clear definition of the scope and boundaries of the water system under study (pond, lake, river, floodplain, etc.), and consideration of potential limitations, especially in relation to open aquatic ecosystems, high variability of water flows or volume and water quality issues. This is particularly relevant in floodplain ecosystems characterized by high variability of water area and flows,

[1] The term 'non-depletive' represents the actual water used by the production systems in maintaining natural hydrological interactions such as evaporation, evapotranspiration and seepage.

notably capture fisheries production reliant on services provided by entire aquatic ecosystems (e.g. for fish migration).

Recognizing the need to select a common measure of water use and requirements, the present study uses the productivity of water and fish as an indicator of the productivity of specific areas of floodplain systems. The general hypothesis is that appropriate aquaculture interventions in seasonal floodplains can improve agricultural water productivity and significantly contribute to basin water management strategies. This also supports the crucial role of floodplains identified in local-level irrigation, groundwater recharge and water table levels (Saraf and Jain, 1996; Dahan et al; 2008).

The study also considers groundwater. The use of groundwater for irrigation, livelihood support and industrial development is comparatively high in the Indo-Gangetic Basin (60% of the total irrigated area in Pakistan, India, Nepal and Bangladesh) and the Yellow River Basin (70% of north China plains) (Mukherji et al 2009). A study by Kijne et al (2003) in the Indo-Gangetic plains of northern India shows that groundwater tables are falling by 0.5-0.7 m per year and that 25% of India's grain harvests are threatened by unsustainable use of groundwater. . A two-way approach is needed to address growing concerns about overuse and degradation of groundwater resources; first, to build capacity of water management institutions at national and local level and of stakeholders at the grassroots level and, second, to re-consider water management options in conjunction with the management of associated natural resource systems such as fisheries and aquaculture. Given that fish production offers ways to both increase water productivity and improve livelihoods, we propose an integrated cross disciplinary framework that builds on developing a spatial understanding of the floodplain landscape, local-level (and multiple) land-water use and management practices, seasonal fish production, ecosystem services and groundwater resources.

The geographical focus of the study is Bangladesh, a poverty-prone and climatically vulnerable area of Asia, where rice and fish are dietary staples and essential to the livelihoods of farmers and fishers (Dey et al., 2005). Over-extraction of groundwater in Bangladesh poses a further serious problem. The high arsenic content of groundwater, first observed in the early 1990s, is now believed to be a substantial risk to people's health (Safiuddin and Karim, 2001; Alam et al., 2002). Many farmers depend on bore wells to meet irrigation needs, a trend that increases rapidly with distance from the catchment or increases in irrigation command area (Shah, 2007). Ingestion of rice is believed to be an important source of arsenic exposure, arsenic levels in rice grain irrigated using groundwater resources ranging from 0.058 to 1.83 $\mu g\ g^{-1}$ (Mehrag and Rahman 2003). A range of innovative biological techniques (biotechnology, genetic engineering) combined with integrated farm-level management has been proposed to reduce exposure (Hughes et al., 1994; Faruqee and Choudhry, 1996; Corson et al. 2007).

Groundwater makes a major contribution to the total irrigated agricultural area in Bangladesh, which has increased from 4% in 1971 to 70% in 1999. This has contributed to the 250% increase in employment in agriculture since 1985 (Mainuddin, 2004). The growing importance of groundwater to the national economy and water supply of Bangladesh, together with the need for increased agricultural production to feed the growing population, has raised the importance of finding innovative approaches to water management that increase food production without increasing pressure on water resources or risks to human health (Solaiman and Belal, 1999; Dey, 2000).

While acknowledging the role of inundated floodplains in recharging local aquifers and maintaining local water tables during the wet season, this study will identify appropriate fish culture interventions in seasonally flooded areas that can contribute to increased floodplain productivity, multiple water use practices and improved management of groundwater resources.

Study scope and area

Community managed aquaculture activities have been introduced in the flooded cropland areas (*beels*) during the wet season, to complement the traditional practice of capture fisheries. Beel/bheel is a local term for a pond with static water mostly created by inundation of low lying lands during flooding[2], when water gets trapped even after flood waters recede, or by inundation of low lying areas during rains, especially during monsoons. Such features are common in the Indo-Gangetic plains of East India and Bangladesh.

In Bangladesh, agroecological zones are characterized primarily on the basis of land levels during floods, physiography and microclimatic regions. Associated variables such as hydro-dynamics and agro-ecosystem type determine the sub-regions [88] and the unit level [535] (Bangladesh Bureau of Statistics, 1998).The information on agroecology is widely used for national and local level planning purposes and more recently in agricultural planning, technology transfer and specific biophysical resource utilization programme activities (FAO/UNDP, 1988). Our sites are representative of the three main seasonal floodplain zones in the country *viz.,* Padma, Tista and Brahmaputra catchments (Figure 2). In addition to the intervention sites, control areas for each site were maintained for comparative analysis.

A) The High Ganges (Padma) River Floodplain extends to 13,205 km^2 of the western catchment of the Ganges River and is predominantly classified as high to medium altitude land, which includes numerous broad and narrow ridges and inter-ridge depressions. The zone also encompasses the northern, central and southern catchments, including the sub-catchment of the Ganges-Mahananda sub-region. High ridge areas often remain above the flood level while lower sections of ridges and the basin are inundated to shallow depths during the wet season. The floodplain has calcareous dark grey and brown, slightly alkaline, soils, reportedly of low fertility (FAO/UNDP, 1988). The site selected for fish culture intervention was the Beel Mail (40 ha), which is in the Mohanpur Upzilla, Rajashahi District. A major portion of the site is open access land during the wet season and is used for cropping on an individual basis during the dry season. The control site from the region is Chandpur beel.

B) **Old Brahmaputra Floodplain** extends to 7,230 km^2, occupying a major portion of the old Brahmaputra catchment [sediments] and the Bansi Valley. The region is characterized by broad ridges and a basin area of irregular relief, representing the old course of the main channel of the Brahmaputra as it was some two centuries ago. The soil is silty to clayey loam, of moderate acidity and is of low fertility. The landscape is highly variable with low, medium-low, medium-high and high, physiography (FAO/UNDP, 1988). Mymensingh in north-central Bangladesh is regarded as the rice bowl area of the country and is considered a promising area for rice-fish culture. It has favorable climatic conditions, low-lying topography, suitable hydrology, fertile soil and readily available human resources (Ahmed and Luong-Van, 2009). The region lies within the monsoon tropical belt with medium to moderate annual rainfall (2,500 mm) and the hydrology is maintained through micro-irrigation channels from sub-tributaries of the Bharamaputra (Barni river). The Kalmina Beel floodplain (Mymensingh Upzilla) covers 33 ha and is privately owned, although during the wet season the inundated floodplains are traditionally used for capture fisheries by both migrant fishers and local inhabitants. The control site from the region is Andula beel.

C) **Tista Meander Floodplain** agroecological zone extends to 9,468 km^2, encircling the floodplain of Atrai, Little Jamuna, Karatoya, Dharla and the Dudhkumar rivers. Most of the area has broad floodplain ridges and a near level basin. The olive brown, rapidly permeable loamy soils in the floodplain ridges, and grey or dark grey, slowly permeable heavy silt loam or silty clay loam soils in the lowlands are moderately acidic throughout, with good moisture retention. Fertility levels are low to medium. The selected site, Angrar Beel (31 ha), is a privately owned seasonal floodplain in Pirgonj Upzilla, Rangpur. The control site from the region is Painglar beel.

At all three sites, prior to the project aquaculture intervention, capture fisheries was the predominant livelihood activity during the seasonal flooded period (from May to November). The rice crop and irrigation units, such as bore wells, micro-irrigation canals and treadle pumps system, infiltrate the entire landscape during the dry part of year (from December to April). The seasonal land is exploited in two phases: dry season farmers grow *boro* rice crop during January-April while from June to December the cropland is inundated (5-6 months) to an average depth of 1-1.5 m. Rainfall raises inundation levels by an average of 50 cm and by no more than 2 m.

Data and Methodology

Floodplain characterization and water productivity

To assess seasonal water availability for aquaculture, we conducted a landscape analysis to characterize floodplain resources. Earth observation data (Landsat TM data [November 11/2000] with a spatial resolution of 28.5 m) was subjected to unsupervised classification in ERDAS-9.2 image processing software to delineate major land cover/use activities in the floodplain. Site-specific attributes, such as the inundation period, effective water area, water inlet-outlet system and harvesting/marketing facilities for the fish, were also determined.

The technological intervention involved two water management arrangements, one to manage the water inflow and outflow, the other to regulate the water retention period. This required construction and repair of dykes, installing concrete circular culverts at inflow and outflow points to maintain water levels in the *beels* between 1.5 and 2 m, the optimal depth for fish production (Haque et al, 2008). Bana (bamboo) fencing was installed at water inlet-outlet points to prevent the escape of stocked fingerlings. Bana mesh sizes (0.5-1.0 cm) the entry of small indigenous species fishes into the *beels* from the main river channel. Both for main sites and the control, locally favored species were stocked as a polyculture, with stocking densities and proportions varying each year. While for the main sites, institutional support to farmer group from local authorities, extension units and national research organizations was arranged, the control site had no such arrangement.

The livelihood based information for both the wet and dry season is derived from household survey records, participatory stakeholder discussions at community and village level. Secondary socio-economic data, such as market fish price, trade fish price, information on irrigation and groundwater consumption, were gathered from local administrative authorities, landowners and farmers.

The framework for water productivity of floodplain aquaculture system was derived from Molden et al. (2003).

a) The production system output is described as a generic production function (based on input-output relationship):

$$\textit{Production System Output (PSO)}_{\text{Seasonal-Floodplain}} = f\,(P1, P2, P3 \ldots Pn)$$

where, PSO is the total output (fish production, in this instance) and *P1, P2, P3…* and the production factors (land, labor, water, capital, energy and other inputs required for production….) and *Pn* represent total production activities. The PSO for seasonal fish production in the floodplains under the regulated conditions can be expressed as functions of floodplain water$_{p}$, flooded land$_{\mathbf{p}}$, feeding$_{\mathbf{p}}$, pumping$_{\mathbf{p}}$, technical arrangements-^{p}, fingerlings-^{p}, stocking-^{p} and harvesting labor-^{p}, institutional support$_{\mathbf{p}}$, marketing cost-^{p}. The superscript '^{p}' refers to paid activities while the subscript '$_{p}$' refers to no-cost activities. To explain PSO we use a simple numeric picking method, where all activities involved in the process are listed (*Pn*) and then classed as paid (I_p) and unpaid (I_u), added and expressed as percentage values. The simple linear equation is an open algorithm that can accommodate both cost and production variables as desired. For the second stage of expression, the equation was monetized with values from input elements.

In short, PSO can be equated using: $[\{(I_u/\,Pn)/(I_p/\,Pn)\}\ /\ \{(C_p/M_p) * 100\}]^t$

At any give time (t); I_p: number of input activities that involve cost; I_u: number of input activities that involve no cost; $C_{p:}$:Total value of I_p; M_p is the market value of total (fish) production. The percentage ratio of C_p to M_p is shown as Net Value Output; PSO integrates the change in ratio of paid and unpaid activities in the subsequent year after fish culture intervention.

b) Fish Water Productivity (FWP) was equated as a function of water output (or seasonal water availability) and changing water output/water availability. The water availability (variable) function is explained in the context of agriculture water productivity from Molden et al. (2003). For seasonally flooded sites in Bangladesh, FWP is defined as total fish production derived from the average water volume required to sustain that production. In order to determine the floodwater availability at each site, we used rainfall (average value in the wet season) as a proxy for water depth for fish culture. FWP is explained pre and post the fish culture intervention in order to compare production 'with' and 'without' the intervention.

$$\textit{Fish Water Productivity (WP)} = \sum^{p}{}_{j=1} \sum^{n} F_P/WA_S$$

- F_P: Total Fish produce (in Kilogram) represents the output derived from seasonal (floodplain) water
- WA_S is the seasonal water availability (volume (depth*height) in cubic meters) represents the water input
- *p* is the number of production systems (in present case p=1 and for concurrent rice-fish production p=2) and *n* is the number of fields/production sites (n=1)

As most of the algorithms used to compute water productivity are inherently crop oriented, the integrated water productivity concepts of Molden et al. (1998) were reconsidered. Water is considered here as a '*multiple-use'* resource, in which the same volume of water is used to produce several crops, as is the case in integrated production systems such as concurrent or alternative rice-fish production systems, or where crop residues are used as livestock feed.

c) Integrated (fish production) Water Productivity of seasonal floodplains *(IWP)*

$$IWP: \sum^{p}_{j=1}\sum^{n}_{i=1} YijAij / \sum^{p}_{j=1}\sum^{n}_{i=1} WijAij$$ (modifed from Molden et al., 1998, and others)

- *Yij:* amount of fish produced in production system j *(seasonal floodplain)* on field *i* (=1) (kg/ha)
- *Wij* is the amount of water (m^3/ha)
- *Aij* is the production area
- *p* is the number of production systems (in present case p=1 and for concurrent rice-fish production p=2) and *n* is the number of fields/production sites (n=1)

In addition, to the accepted method of calculating water productivity applied above, we re-calibrated the gross value productivity equation. The gross value accounts for the economic value of the production systems at multiple levels *i.e.* local, national or international supply chain.

d) Gross Fish Productivity of seasonal floodplain = $(\Sigma^{N}_{i=1} AiYi \quad P_i/P_b)\ P_w$

where *Ai* is the fish production area, *Yi* is the yield of fish in field (*i)*, here i=1; P_i is local price of fish from field (i); P_b is the local price of the main fish (carps are the main locally-grown, nationally/regionally-traded fish species), P_w is the trade value of the cultured fish crop at national level prices and *N* is the number of fish species (here taken as clusters) in the production system. The equation also encompasses the indigenous fish species as a cluster along with the culture produce. For the culture produce, the main species (carps) are considered as separate variables, while the secondary species, which represent a small fraction of the total produce, are treated as a group/cluster. The details are shown in table 3.

Seasonality and groundwater interaction

The aerial statistics from landscape characterization were computed with biome values coefficients defined by Constanza et al. (1997) in order to explain the seasonality of ecosystem services and benefits derived from the floodplains. Coefficient values for each land-use class corresponding to one of the biomes and the total value of ecosystem services were calculated using the equation of Kreuter et al. (2001). Additionally, each land use category was classified by type of ecosystems service, such as regulating, provisioning, supporting, and cultural, as defined in the Millennium Ecosystem Assessment (2005). Changes in ecosystem services values between wet and dry season were estimated from the differences in the estimated seasonal values for each land-use category.

$$ESV = \Sigma (A_k \times VC_k)$$

where,

- ESV is the estimative of ecosystem services value,
- A_k is the area (ha) and
- VC_k is the value coefficient (US$/ha year) for the land-use category *k*.

Information was gathered on the number of irrigation cycles for rice production, the number of bore wells, number of days each field is irrigated using bore wells, the proportion of remnant fish culture water used for irrigation, and statistics on rice and fish production pre and post intervention.

We also compare the changing trends in floodplain use during the wet season and its impact on the subsequent dry season production system *i.e.* rice production in the case of multiple water use. Impact is measured in terms of changing use of groundwater for irrigating rice nurseries and the transplanted paddy fields as a result of the fish culture intervention during the flooded period. The case is specifically explained for Kalmina Bheel in Mymensingh. Here, entire communities or individuals (farmers, fishers, etc.) from around and adjacent to the *beels* were collectively involved in culturing fish in the seasonally inundated floodplains. For example, a total of 174 beneficiaries were engaged, more than 50% being landowners (97), 30% landless (52) and the rest traditional fishers (25). The initial start up cost for an aquaculture system can be prohibitive for individual poor households, thus a community-based approach was selected to allow poorer households to participate in, and benefit from, aquaculture production. Additionally, Haque et al. (2008) explain the role of institutional linkages that facilitated pre-negotiated benefit distribution through the formation of site-specific Floodplain Management Committees (FMC) and monitoring by Project Implementation Committees (PIC).

Results and discussion

Floodplain characterization and water productivity

Floodplain characterization at landscape level describes the resource pattern at basin scale, the distribution of major production systems and the land cover/use pattern, described in depth for Padma floodplain with the spatial representation of the receding wet season (Figure 2a & 2b).The land cover categories in the basin, *i.e.* water body/flooded area and shallow water area with surface vegetation, accounts for more than 40% of the total analyzed area. The inundated area with grass/shrub land represents a further 13.7% (Figure 3a). The seasonal flooding event in the basin impacts more than 55% of the floodplain, primarily the low-lying regions, during the wet season.

The spatial analysis identifies nearly 40% of the basin area as cropped lands in November, primarily the medium to high altitude areas of the basin or the topographical formations that facilitate hydrological flow during the wet season. The basin wide landscape analysis provides a good insight into how to scale the fish-targeted interventions in the seasonal floodplains. For example, if it is wished to scale up the fish culture intervention throughout the High Ganges floodplain agro-ecosystem, which inundates more than 30,000 hectares, the low to medium altitude areas have the optimum hydrology and topology to support the intervention. An agro-ecological perspective provides an overview of the geographical and the ecological boundary of the floodplain ecosystem; this is crucial to understand the variation and appropriateness of the intervention at the basin-scale and assists the cross-scaling process. However, the appropriateness of localized features such as field dykes and embankments, together with social inclusion and exclusion and the size and equitability of benefits sharing remain important determinants of the success of such interventions.

In the water productivity analysis, functional attribute, PSO, is computed from the sum of traditional capture fisheries and the fish culture activity introduced through the project and the final benefit derived from fish production. It was observed that nearly 33% of total activities involve no additional cost in Bheel Mail in 2007 and it increased to 47% in 2008 (Figure 5a). The net value output in Figure 5b, shows the percentage of the monetary profit value. The range for Kalmina Beel (117% in 2007 to 155% in 2008) is compared to Bheel Mail (88% in 2007 to 107%) in 2008. Differences can be explained on the basis of differences in ownership status of the beel. While Kalmina floodplain is completely under private ownership without any cost of lease involved, Bheel Mail (40 ha) floodplain is a public ownership land with public water bodies (15.2 ha), surrounded by privately owned land (24.8 ha). The fish culture involves a lease value *i.e.* 154,580 Takas ($ 2232) in 2007, which increased to 177,744 Takas ($2265) in 2008. Interestingly, the PSO values for the two floodplain sites are broadly comparable, ranging from 19 to 24%.

Fish Water Productivity, a function of inundation level, is projected before and after intervention,, illustrates the increase in fish production in two successive years following the fish culture intervention, with the most promising result being from Kalmina Beel (Figure 6). For Angrar Beel, we observed a decline in fish production in the second year after the intervention. Here, the culture experiment was temporarily discontinued because of reported community conflict and as a result the produce value for the second year is primarily derived from capture fisheries production. The calculated values for control sites reflect stationary production for subsequent years after intervention as reported in case of Andula and Painglar beels or decline in production as at Chandpur beel. Thus, maximizing the benefits of fish culture requires that both technological arrangements and the strong institutional and policy support are in place.

The integrated and gross water productivity value is a concept derived from Molden (1998). While the integrated fish production value takes account of production area and water availability as primary variables, the gross fish productivity emphasizes the economic value of the produce (fish) locally /nationally/internationally. The underlying concept can also be applied to multiple fish production systems such as concurrent rice-fish culture systems or similar integrated-agriculture-aquaculture systems. For both Kalmina and Beel Mail, the integrated fish based water productivity value shows an exponential ($R^2 > 0.9$) rise following the fish culture intervention. For Angrar Beel, an increase is observed after the first year of intervention, followed by a decline in the second year for the reasons given above (Figure 7a).

The fish based gross water productivity value evaluates production based on the site-scale supply chain. Local demand, market accessibility, national and international trade value of the produce and the institutional support are critical variables governing gross water productivity value. The value increased at all three sites, but to varying degrees. Bheel Mail shows exceptional high values owing to the comparably high fish produce after intervention (24989 kg from 40 ha), compared to Kalmina (6469 kg from 33 ha) and Angrar (6663 kg from 31ha) bheel (Figure 7b).

Seasonality, ecosystem benefits and multiple water use

The site-scale land cover use statistics explain the seasonality of land use in the Bheel Mail floodplain. The pattern of activities clearly switches between crop culture during the dry season and water inundated croplands used for fish related activities in the wet season (Figure 3b and Table 3). By providing dollar equivalent value for site-scale statistics, the seasonal ecosystem value (ESV) of the floodplain ecosystem was estimated. The value of 'floodplain' as an ecosystem resource is inherently ranked high (rank value = 1) both for wet and dry season (e.g. the wet season ESV is $US56,7820/ha/y) as the figure incorporates ecological, hydrological and other environmental values of floodplain, such as a flood buffer, habitat for flora and fauna, etc. The portion of the floodplain land used for cropping during the dry season has a rank value of 3 in the dry season and 4 in the wet. A further evident landmark during the dry season is the deep/shallow tube wells and seasonal (micro) irrigation channels that traverse the croplands.

Aquaculture water management and groundwater interaction

Capture fisheries and aquaculture dominate livelihood activities during the flooded period, from May to November. 'Boro'(winter) rice is grown from November to May, transplanted mainly to low lying rain-fed swampy or rain-fed flood-prone areas, which are not cultivated during the rainy season due to high soil saturation and inundation. 'Aman', or the main wet season rice crop that survives inundation, is planted from June to November in certain areas. The irrigation network of bore wells, micro-irrigation canals and treadle pumps supports the dry season crop (Aus or summer rice) from February to July. Dey and Prein (2004) described fish culture as concurrent with Aman rice cropping (concurrent system) or as occurring between summer and winter rice (alternating system).

We present the case for an alternative system where fish is cultured in seasonally flooded croplands with inundation levels (water depth >1 m) unsuitable for crop production. The aquaculture water management and ground water interaction scenario is illustrated using Kalmina Beel, wherein Boro rice is predominant in lowlands with some areas adjacent to low lying areas in mid-low and mid lands planted with Aman rice. A total of 5-6 (ground water pumping) irrigation cycles is needed for Boro rice and 1-2 irrigation cycles are needed for wet season Aman rice.

Following the project intervention, 16-35% of the irrigation cycles needed to grow irrigated rice in the dry season were replaced by use of seasonal flood water. In parallel, the technological intervention for water regulation for fish culture in low lying seasonal floodplain met almost all the irrigation needs for the peripheral Aman rice. In 2008 the intervention site had 34 low lift pumps that transferred the water remaining after fish harvesting, for irrigation. Residents surveyed from Kalmina (mainly landowners) stated that they relied completely on bore well pumping for irrigating the dry season rice before the intervention because the un-regulated dispersal of flood water within a period of two to four months (May-August) of the peak rains. The rice nursery and transplantation that followed was irrigation dependent and the irrigated season lasted from September to April.

The intervention facilitated selective water channeling and the installation of culverts to regulate inflow-outflow, and improved relations with local authorities. The standing water period increased to six-seven months (May-December) while the ground water used for irrigation was substituted by the use of residual flood water. Sixty five percent of the respondents from Kalmina indicated that the pattern of irrigation changed following the intervention and that ground water pumping for irrigation has decreased. It can also be argued that the impact of seasonal aquaculture on crop production activity also results in increased nutrient flow, improved drainage, enhanced soil moisture and reduced exposure to arsenic.

Conclusion

This study clearly shows that seasonal aquaculture supported by the management of floodplains for multiple-use of water significantly increased the productivity of rice-fish production systems at the selected sites. The improvements resulted from pilot-scale community-based management of fish culture at the study sites. While it is likely that similar interventions are broadly applicable in similar floodplain systems, net economic benefits and the way that these benefits are shared, can be expected to vary.
Landscape pattern and topography were important determinants of hydrological flow and the interactions that can potentially support or undermine fish culture activities during the wet season. Technical arrangements to regulate seasonal flood water successfully extended the culture period, and increased rice and fish production in the study sites. In addition appropriate local water management strategies that are supported by local authorities, and that take account of the biophysical and ecological characteristics of floodplains, typically their high variability and seasonality, can play an influential role in enhancing floodplain productivity. While the above strategy is more appropriate for publically owned lands, the inclusion of local authorities for fish culture management in case of privately owned lands can be challenging.

The analysis of multiple-use of water for rice and fish culture also identified options in the use of multiple sources of water: surface and groundwater. The management of floodplain seasonal surface water for aquaculture has generally contributed to the supply of water for agriculture in the dry season. Notably, a proportion of groundwater based irrigation cycles has been substituted with residual aquaculture water, which is waste free in this type of aquaculture. Susceptibility to potential contamination by arsenic arising from groundwater use has also been reduced. In economic terms, the wet season aquaculture experiment helped reduce the cost of rice production in the subsequent dry season, and the multiple-use of water resources led to an overall increase in economic benefits at community level, and showed promising potential for up-scaling at catchment level.

Floodplains provide a wide range of ecosystem services, and provisioning services in particular, which are subject to competing claims for rice and/or fish production. Enhancing the productivity of aquatic floodplains in a sustainable and resilient manner calls for the diversification of agriculture and fisheries production systems, the multiple-use of seasonal surface water, as well as the conjunctive use and management of surface and groundwater in the case of Bangladesh floodplains. The adaptation of agricultural water management along with fisheries and aquaculture interventions can play a significant role in reducing the impacts of rainfall variability and local climatic shifts on the productivity of floodplain ecosystems.

In general the authors highlight the value of multiple resource use approaches to enhance the productivity of floodplain wetlands in a sustainable and resilient manner. In the Bangladesh floodplain this implies a major re-consideration of agricultural water management options to include other sources of food such as fish produced by capture fisheries and aquaculture.

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List of Tables and Figures

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Table 1: National level inundation statistics for Bangladesh Floodplains with projected potential for seasonal fish culture (adapted from WMO and GWP, 2003)

Land Category	Area in hectare	% National area	Land Type Description	Seasonal Flooding Extent	Suitability for seasonal aquaculture
High Land	4 199 952	29	Land above normal inundation	Minimal less than a month	Low
Medium High Land	5 039 724	35	Land normally inundated up to 90 cm deep	Low–short duration (more than one month but less than three months	Moderate
Medium Low Land	1 771 102	12	Land normally inundated up to 90-180 cm deep	Medium to Moderate-medium duration (more than three months and extends to five months)	High
Low-lying Land	1 101 560	8	Land normally inundated up to 180-300 cm deep	High-long duration (more than five months)	Medium
Very Low-lying Land	2371288	15	Land normally inundated deeper than 300 cm	Difficult to manage	Difficult
River channel and catchment area			Seasonal / Perennial	Confined	-

Table 2: Wet and Dry Season Resource Use Matrix for project sites in two floodplain agroecosystems of Bangladesh including control site (shaded) (Data Source: Socioeconomic survey/ field observation)

Land /Water resource use activities	**Wet Season Floodplain activity**				**Dry Season Floodplain activity**			
	Beel Mail-FI	Chandpur F1C1	Kalmina F2	Andola Control F2CE	Beel Mail F1	Chandpur Control F1C1	Kalmina Floodplain F2	Andola Control site F2CE
Cropland	++++	++	++	++	+++++	+++++	+++++	+++++
Community Based Fish Culture/Fish Culture	+++++	++	+++++	-	+	-	+	-
Fishing	+	++	+	++++	-	-		-
Duck Farming	+	+	+	+	++	++	++	++
Vegetable production	+++	++	++	++	+++	++	+++	++
Water /Irrigation Channels	+	+	+	+	++	+	+++	-

+++++ (>80% and less than 100 of the area); ++++ (> 60% and less than 80); +++(> 40% less than 60); ++ (>20% less than 40);+ (>1% less than 10%); -:No activity

Table 3: List of major activities involved in fish culture experiment in seasonal floodplains along with the cost and no-cost profiling (all values in Bangladesh Takas).

Activities	**Study Sites in Seasonal Floodplains**						Cost of the activity (Takas)
	Bheel Mail (Rajshahi)		Kalmina (Mymensingh)		Angrar (Rangpur)		Observation/ Comments
	2007	**2008**	**2007**	**2008**	**2007**	****2008**	
Land availability	Seasonal flooded croplands and public land-common property resource (lease value involved).		Privately owned land no lease value involved		Privately owned land no lease value involved		
	154580	177744					
Water availability	Seasonal flooding		Seasonal flooding		Seasonal flooding		During wet season , normally inundation period varies between 3-6 months
Technical arrangements	Bana fencing (Culvert /bridge already existing)		Bana fencing, ring culvert and earth (dyke) work (Culvert/bridge already existing)		Bana fencing and earth (dyke) work (Culvert /bridge already existing)		Value of the technical intervention varies with landscape and topographical feature of the landscape
a) Ring Culvert	-	-	15000	6000	-	-	
b) Dyke preparation	-	-	4000	5000	10000	-	
Boat purchase & maintenance	10000	-	10000	4000	15000	-	-
Fingerlings (included labor charge)	144000	126050	89502	135567	121245	-	Site specific, in Bheel cost decrease as of ample availability
Labor charge to main water regulatory arrangements	5000	5000	3782	2540	5000	-	Variable in Kalmina Bheel
Feeding	-	-	-	-	-	-	No cost for all sites
Guarding	21000	21000	21000	25200	Managed by community	-	Different arrangement by different communities
Cost of the Guard shed	5000	5000	3000	3000	3000		More or less constant
Harvesting (labor charges)	277775	317642	52039	91473	47776	-	Higher in Bheel mail as of comparatively large area
Remnant Water Pumping	-	-	-	-	-	-	Used for irrigating rice field and nurseries
Marketing cost(transport & toll)	6000	6500	*	*	3500		On –site marketing arrangement in case of Kalmina Bheel
Institutional support ;	Incorporated in the lease value		Informal support without any binding obligation				
FMC cost for meeting	5000	5000	3000	3000	2000	-	Varies

*fish was marketed in the floodplain sites and the buyer came in the floodplain sites. No cost was involved in marketing

**Angrar bheel was not stocked for the year 2008 due to reported conflict among the group members

Table 4: Example of fish species clustering in Kalmina Beel. Clustering was done to estimate Gross Fish Productivity of seasonal floodplains. The shaded rows represent the carp cluster

Species	Before Intervention Wt(kg)	After intervention 1st year (2007) Wt(kg)	2nd year (2008) Wt(kg)	Cluster
Silver carp	0	1701	4669	Cluster A
Common carp	32	1359	3233	
Catla	11	1672	1720	
Rohu	6	116	637	
Mrigal	0	95	0	
Carps	**49**	**4943**	**10259**	Total Five Species
Tengra	32	34	45	Cluster B
Magur	5	9	12	
Shing	6	9	8	
Pabda	0	3	4	
Shoal	12	15	35	
Taki	15	17	22	
Ragua	0	2	5	
Mola	124	135	211	
Rani bow	0	1	2	
Dela	39	36	49	
Chela	4	7	9	
Darkina	10	16	23	
Puti	453	403	760	
Chanda	88	95	280	
Bele	8	28	22	
Gutum	8	23	28	
Meni	2	5	6	
Koi	3	5	7	
Colisa	5	15	18	
Guchi	38	47	55	
Baim	18	25	27	
Chingri	595	585	653	
Kakila	2	5	7	
Potka	0	2	2	
Foli	2	4	5	
Non-carps:	**1469**	**1526**	**2295**	Total 25 Species
Grand Total	**1518**	**6469**	**12554**	

Table 5: (A) Seasonal landscape analysis and change in land cover/use for Bheel Mail ; (B) ecosystem value estimates for wet and dry season

A : Resource use pattern at site level for (Area in Hectare)				
Floodplain Resource use Activity	Area in Wet Season	Area in Dry Season	Change in Activity from Wet to dry	[1]Pattern and gradient of Change
Cropland	7	27	20	↑↑↑↑
Fish Culture / Capture Fisheries	29	3	26	↓↓↓↓
Vegetables	3.5	6	2.5	↑
Irrigation Channels	0.4	3.5	3.1	↑
Deep Tube Well/ Shallow Tube Well	0.1	0.5	0.4	↑
Total Area	40	40	- -	

B : Ecosystem benefit analysis for Bheel Mail floodplain ecosystem									
Land /Water Resource use Activity	Equivalent Constanza´s et al. biomes	MEA (2005) ecosystem function	(US$/ha/ year)-use coefficient	ESV of the food plain in wet Season	%	Rank	ESV of the food plain in dry season	%	Rank
Cropland	Cropland	Provisioning	92	644	0.1	3	2484	2.6	4
[2]Fish Culture / Capture Fisheries	Floodplain	Provisioning Regulating Supporting Cultural	19580	6E+05	99.1	1	58740	61.3	1
Vegetables	Cropland	Provisioning	92	322	0.1		552	0.6	5
Irrigation Channels	Lakes /River/Channels /water Source	Regulating Supporting Cultural	8498	3399	0.6	2	29743	31.1	2
Deep Tube Well/ Shallow Tube Well	Lakes /River/Channels	Regulating Supporting	8498	849.8	0.1	3	4249	4.4	3
				6E+05	100.0	3	95768	100.0	

[1]The direction of arrow in section A represents the pattern of change, with the upward arrow indicating an increase in activity during the dry season, compared to the wet season , while the number of arrows in the column show the gradient . For example, each arrow represents a change between 1-5 hectares.

[2] Fisheries is the natural harvest of the floodplain with a maximum dollar value in terms of ecosystem service.

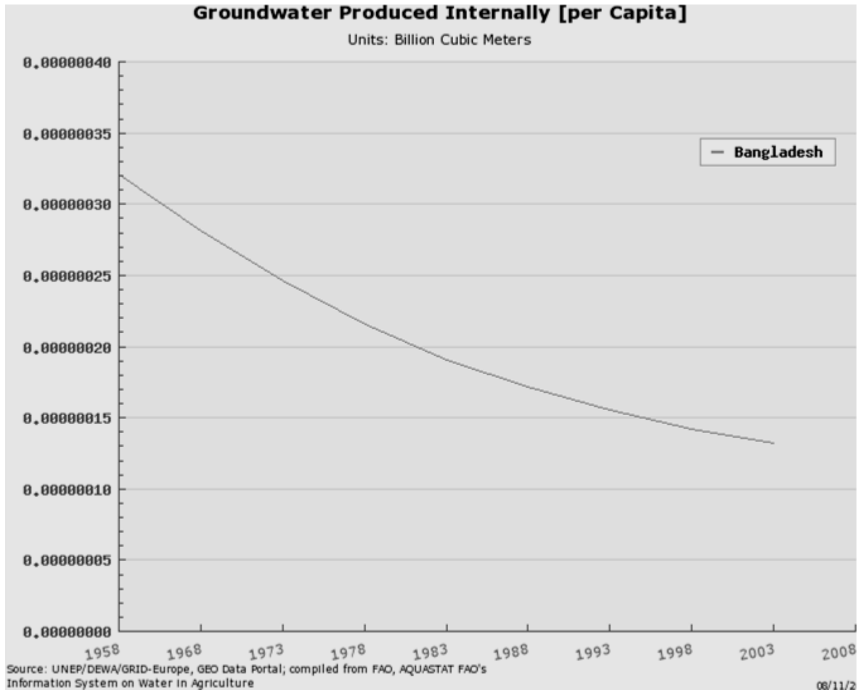

Figure 1: The trend of ground water production in Bangladesh projected using FAO-Aqua stat data

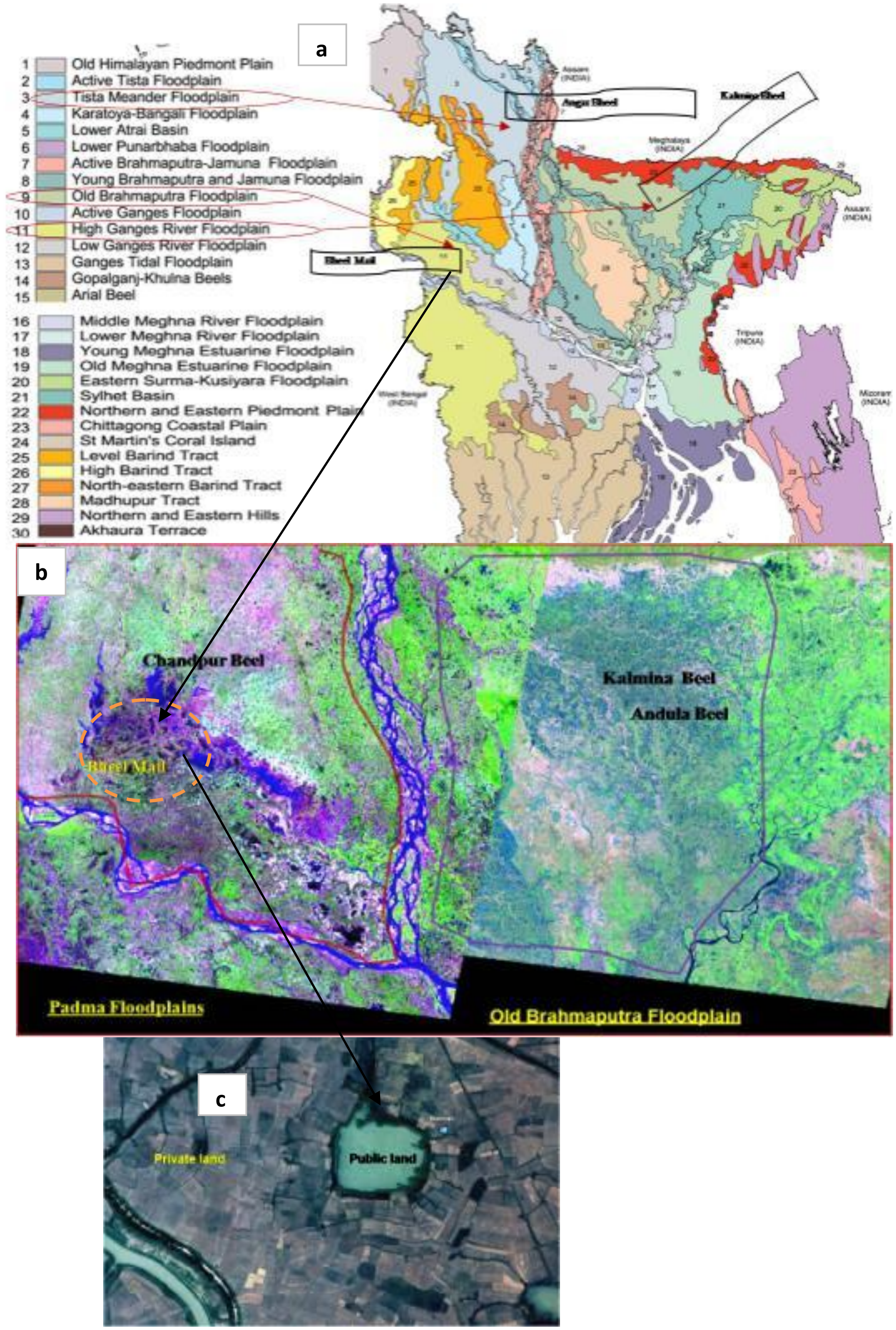

Figure 2: a) Agroecological zoning, study sites in Bangladesh (Source: Bangladesh Agriculture Research Center, Dhaka b) The Padma (November 2000) and Brahmaputra (February 2001) floodplains and site locations in Landsat data (spatial resolution: 23.5m); c) the Google profile of Bheel mail, illustrating the public and private land distribution in the beel area

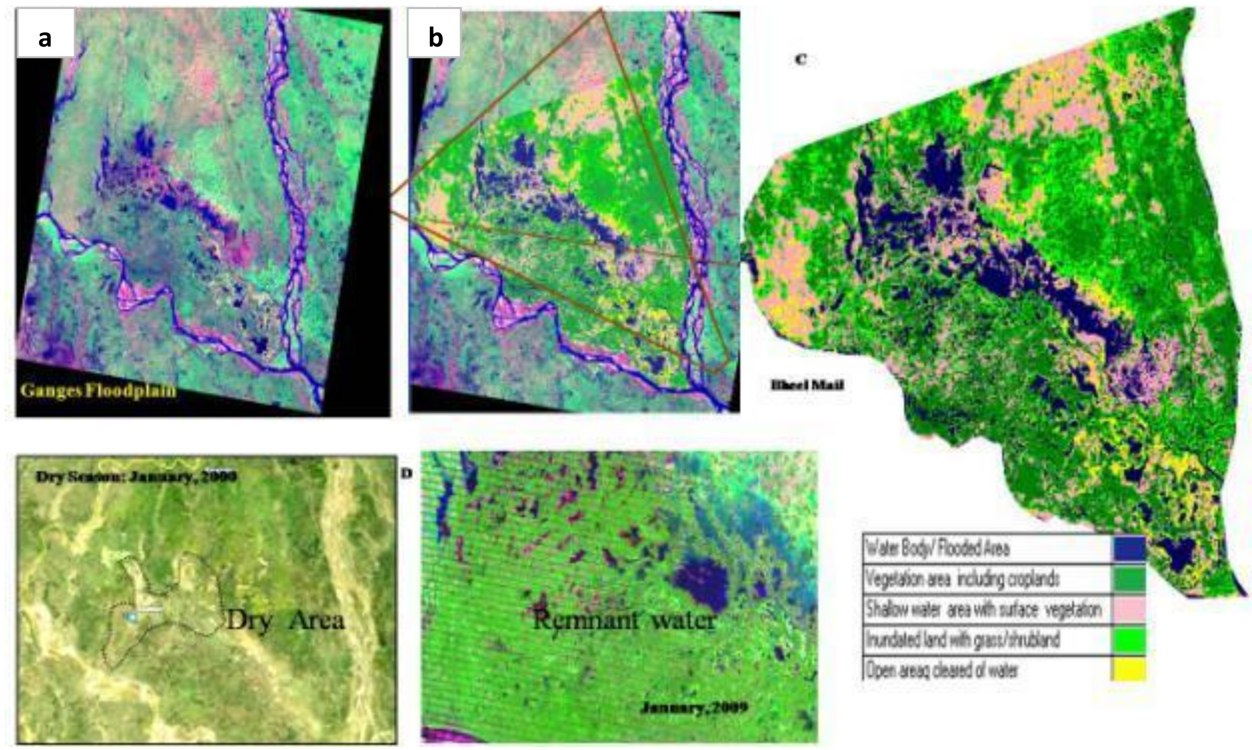

Figure 3: a) Landscape level characterization for Bheel Mail in Ganges (Padma) floodplain: Landsat TM true color composite November 2000; b, c) Classified image with land cover units; d) scenario from January 2000 and 2009, depicting the change in remnant water (blue) regulated by intervention.

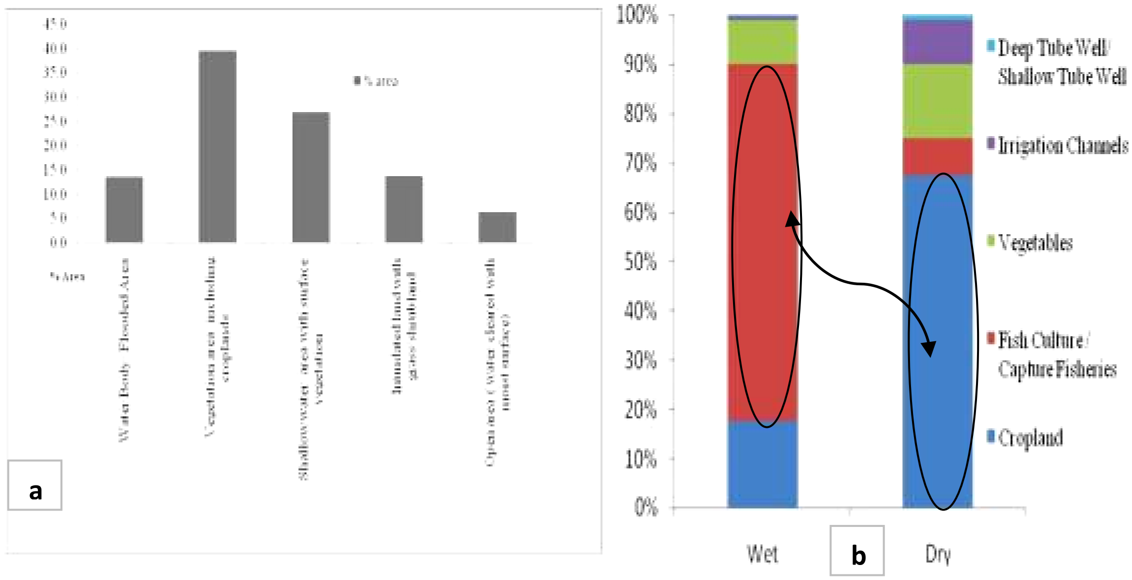

Figure 4: (a) Areal statistics for Bheel Mail (November-tail end of wet season) and (b) and ecosystem benefit analysis for wet and dry season, highlighting the switch in use of floodplain for cropping and fisheries related activities in the different seasons.

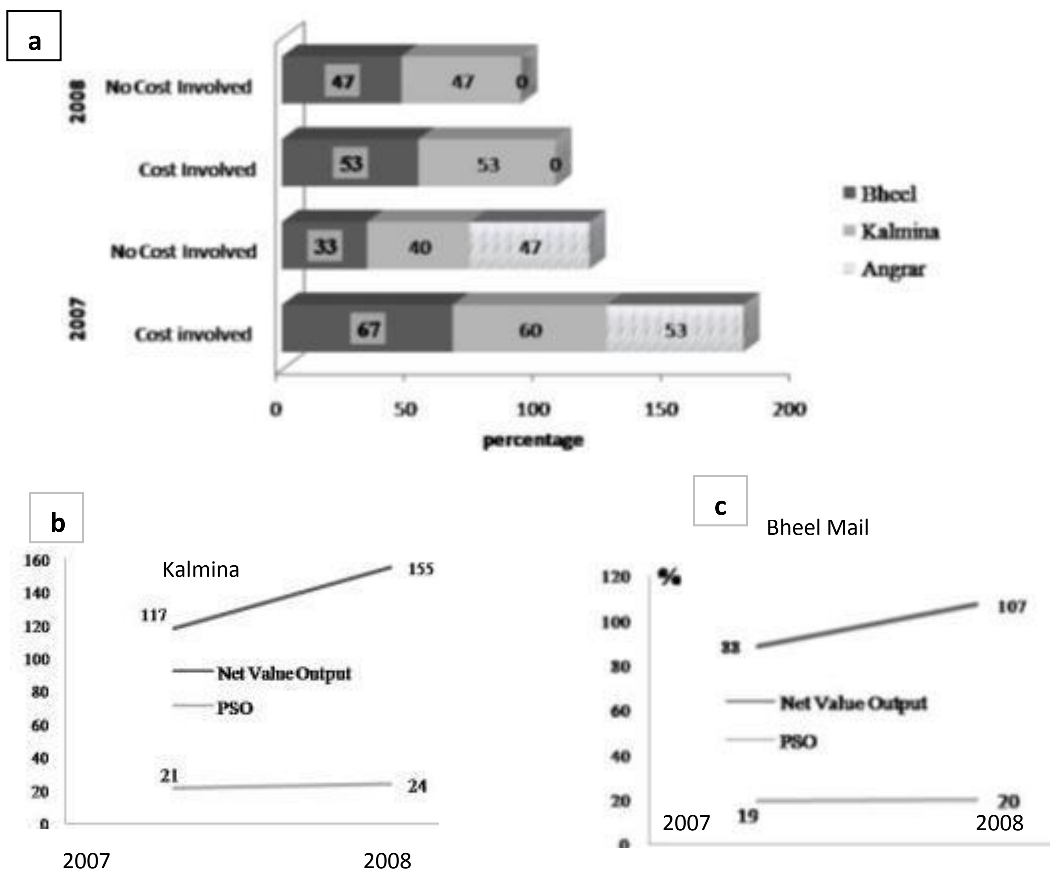

Figure 5: Production System Output depaicted as consisting of two steps; (a): the changing pattern on ‘cost’ and ‘no cost’ activities for seasonal; fish production in subsequent years for all three sites; (b ,c) the ratio of the changing pattern incorporated to calculate the performance of the production system (PSO) for Bheel Mail and Kalmina Beel. The net value represents the monetized profit value.

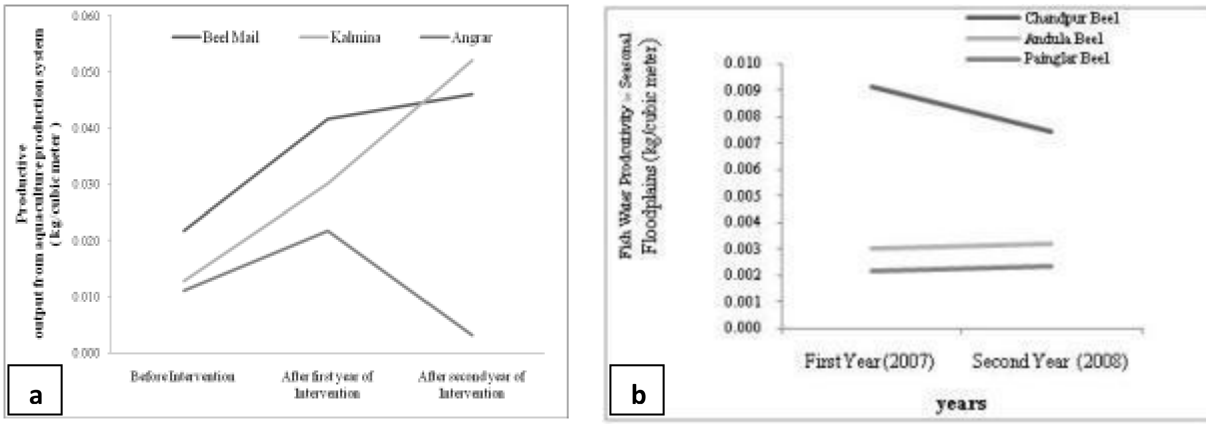

Figure 6: Aquaculture based water productivity analysis for representative seasonal flood plain sites in Bangladesh; (a) Fish water productivity at main sites before and after intervention; (b) Fish water productivity at the control sites

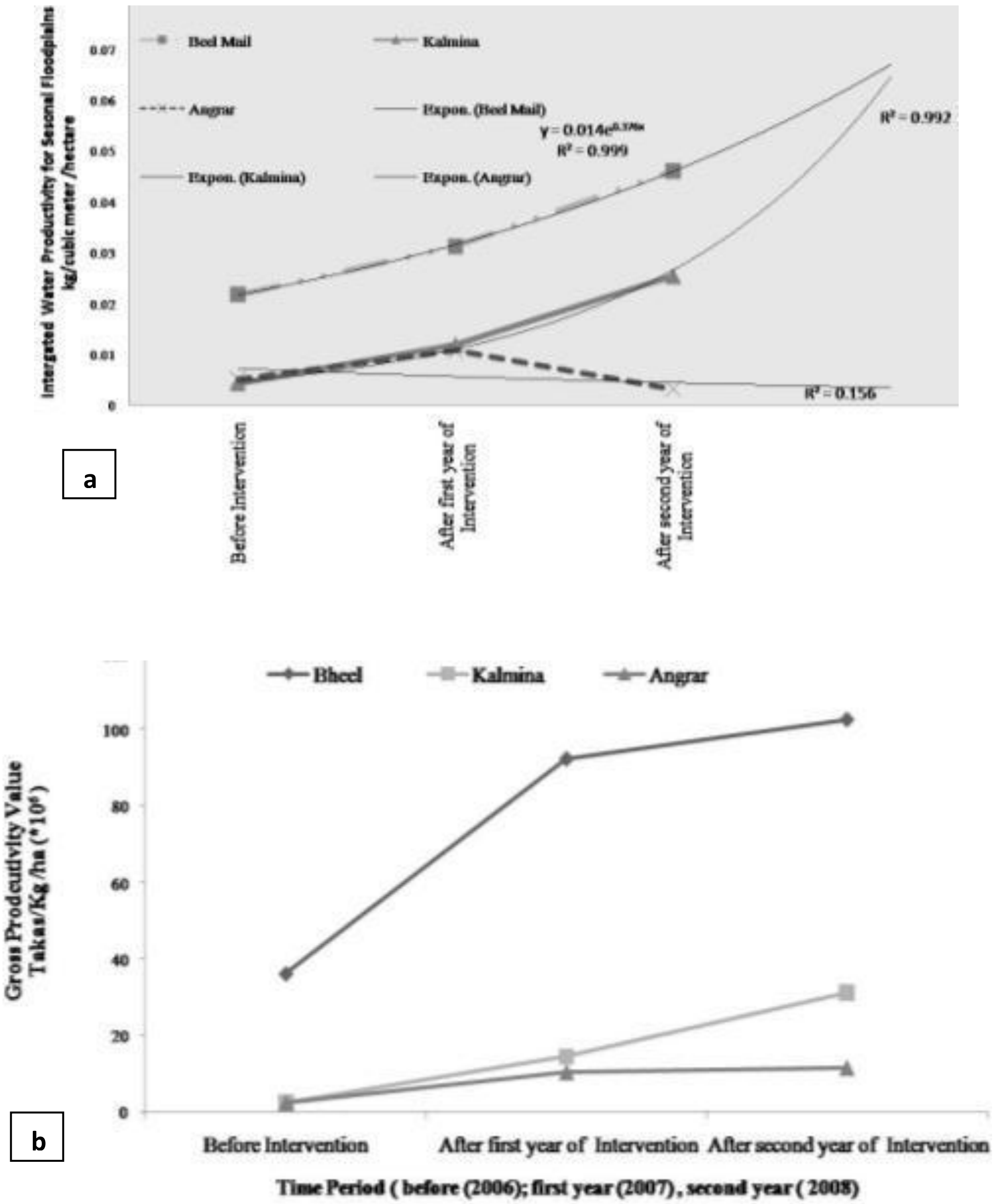

Figure 7: (a) Integrated Water productivity in context of fish culture intervention in seasonal floodplains; b) Gross Fish Productivity of seasonal floodplain for the main floodplain sites