MACH

Technical Paper 7

Extent and Duration of Inundation and its Relation with Fish Production in Hail Haor

Management of Aquatic Ecosystems through Community Husbandry

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CARITAS Bangladesh

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Abstract

Hail Haor is a large floodplain basin surrounded by hills on three sides. It is almost cut off from other open water systems due to these hills plus roads and embankments along the other side. It is located in the district of Moulvibazar. The major source of water in the haor is local rainfall and hilly stream flows. The water area of the haor varies from a maximum of 12,000 - 15,000 ha in the wet season to a minimum of 3,000 ha in the dry season. The haor is an important fishery which is the major source of livelihood of many people of the area. Due to over fishing and loss and degradation of fish habitat, the fish production in the haor had been declining. Since 1999, the USAID-funded MACH project has worked to improve fisheries management in the haor. The local community and local government have worked together to ensure sustainable fish production and improved livelihoods for haor users. Under the project key fishery management interventions have been habitat restoration, establishment of fish sanctuaries, and adoption of norms such as closed seasons and an end to dewatering in various parts of the haor.

During the project period fish production and inundation extent and timing have been carefully monitored and were found to fluctuate between years. An attempt has been made to see if the hydrological regime of the haor influences fish production. The study found that early commencement of pre-monsoon flooding in April-May (the spawning season of fishes) influences fish production - i.e. the earlier is the flooding the higher is the fish production in that year. Total annual inundation, maximum monthly inundation and extent of flooding during April-May were all found to explain variation in fish production (significant correlations). However, variations in the minimum dry season inundation of 2,000-3,000 ha that existed during 1999-2005 did not have any major impact on production implying that this was sufficient to sustain the range of fish production encountered. Although there is some indication that fish production was higher in later years of similar hydrology to the baseline year, the apparent doubling of fish production in 2004 compared with 1999 is likely to be due more to high floods in 2004 than to improved management. Although indicative of some positive project impacts, because of the importance of between year hydrological variations the study would benefit from more than six years of data.

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1. Introduction

During the wet season Bangladesh has vast inland water resources in the form of rivers, canals, beels, haors (large depressions), baors (ox-bow lakes), a large reservoir, and seasonally flooded lands, with a high potential for fish production. The combination of the huge quantity of run off water from the large catchment area of the main rivers and high local rainfall overflows the banks of the rivers and inundates vast low lying areas every year. About two-thirds of the country is flood prone and usually up to a third of the total country remains under water for 4-6 months a year. Nutrient inflow with water from local and external catchments makes the water very fertile and productive for growth of fish and other aquatic organisms. The floodplains are a very important component of the inland fish production system. At the onset of the rainy season many fish species and other aquatic organisms migrate from the rivers to the floodplain for breeding, feeding and growing. Some of the fish are harvested, some return back to the rivers, and some remain or are trapped in perennial water bodies (beels and canals) in the floodplain. But due to man made and natural causes such as over fishing, habitat loss and degradation by flood control and drainage projects, industrial and agro-chemical pollution, and siltation, fish production in the inland open waters has decreased over the last four decades.

Flood control and drainage has increased agricultural production, but the migration of fish to and from the floodplain has been blocked by embankments and sluices, contributing to the decline of inland fisheries in general and floodplain fisheries in particular. These projects have also reduced the water area and water depth in the floodplain affecting the aquatic system. Siltation, drainage and irrigation activities have drastically reduced the dry season refuges for fish in the floodplain. Now many water bodies dry up or do not retain sufficient water for survival of brood fish that would breed and multiply in the floodplain the next monsoon. Again the reduction of dry season water flow in the major river system, particularly in the Ganges system due to construction of Farakka Barrage in India, has also affected the inland fishery resulting in a decline of fish stock particularly the hilsha. Major carps have also been severely affected by this, embankments, and spawn collection.

In the natural open water system, the aquatic yield depends on many factors such as discharge and flow of water, extent of surface water, depth, duration of inundation and productivity of water and soil. The hydrological regime of inland water in river and floodplain is very dynamic and determined by many factors such as rainfall, runoff from upstream drainage systems, etc. The key changes in the inland river and floodplain system in Bangladesh are a serious reduction of water area and deterioration in dry season fish habitats affecting the fish stock and thereby reducing recruitment (below sustainable level) in the wet season when sufficient water is still available.

In order to restore fish production in the inland open waters on a sustainable basis the Government has taken up various development projects. Management of Aquatic ecosystem through Community Husbandry (MACH) is one such project working for sustainable management and restoration of inland fisheries and wetlands in Bangladesh. The project's main characteristic is a holistic community based approach to aquatic resource management in the entire ecosystem. The project has been implemented for seven years since 1999 with funding support of USAID in three floodplain ecosystems: Hail Haor, Turag-Bangshi floodplain, and Kangsha-Malijhee floodplain. Different management interventions have been taken up in those floodplain ecosystems. General increases in fish production, but with some remarkable fluctuations in different years, have been observed during the project implementation period.

It is likely that production is influenced by both the interventions and hydrological parameters. Hence it was of interest to investigate inundation extent and how fish production varied in relation to it. Hail Haor was suitable because it is a single isolated depression and the hydrological regime of the haor (the extent and duration of inundation, water depth, etc.) is well defined and easily measurable. The water area of the haor is mainly influenced by local rainfall in the haor proper and the surrounding hills. Recruitment of fish from outside is reduced now as the connection of the haor with outside rivers and floodplains is controlled by embankments and roads.

This paper analyses floodplain fish catches in Hail Haor, one of three sites of the MACH project, focusing on the hydrological regime, extent and duration of surface water and its relation to fish production in the haor.

2. Description of Hail Haor

Hail Haor is a floodplain basin located in Sreemangal and Moulvibazar Upazilas of Moulvibazar district. The Haor is surrounded on three sides (east, west and south) by hills and one side (north) is a plain with a flood control embankment. Water originates from the surrounding 350 small hill streams and the Lungla/Balisashi River. The major sources of water in the haor are rainfall and stream flow from the surrounding hills. Hail Haor's only discharge point is the Gopla River which connects directly to the Upper Meghna. In the rainy season the haor basin becomes a large single body of water with a maximum area between 12,000 and 15,000 hectares in different years. In the dry season, the water area of the haor reduces to about 3,000 to 4,000 hectares, or even less in some extreme years, when water is isolated in the different beels and rivers. Maximum and minimum inundation is given in Figure 1. The catchment area of the haor is about 60,000 hectares. On three sides on the hills there are a chain of tea gardens, pineapple fields, groves of rubber trees and remnants of natural forest most of which has been cleared. Level areas above flood level are intensively cropped (2-3 crops per year) with rice monoculture. Fishing in the haor occurs year-round. During the wet season, subsistence and gill net fishing predominate. Larger fish are caught during the dry season from katha (brush pile) fishing and by dewatering the beels (deeper depressions within the haor). The population of the area is about 160,000 in 60 villages. About 84 percent of households have some involvement or dependence on fishing and 53 percent are full time fishing households (MACH, 2001).

Table 1 : Total water area of Hail-Haor in 2002.

Type of Water body	Water Area in Rainy Season (ha)	Water Area in Dry Season (ha)
Beel *	3,023.7	3,023.7
River *	151.06	151.06
Canals *	208.78	208.78
Floodplain	11,440	-
Total	**14,926**	**3,486.2**

* areas shown in government records
The floodplain area is the remaining inundated area from GIS analysis presented in this paper.

3. Objective of the Study

The objective of this study was to see how the duration and extent of inundation in the haor influence the overall fish production of Hail Haor, considering the interventions under the MACH project.

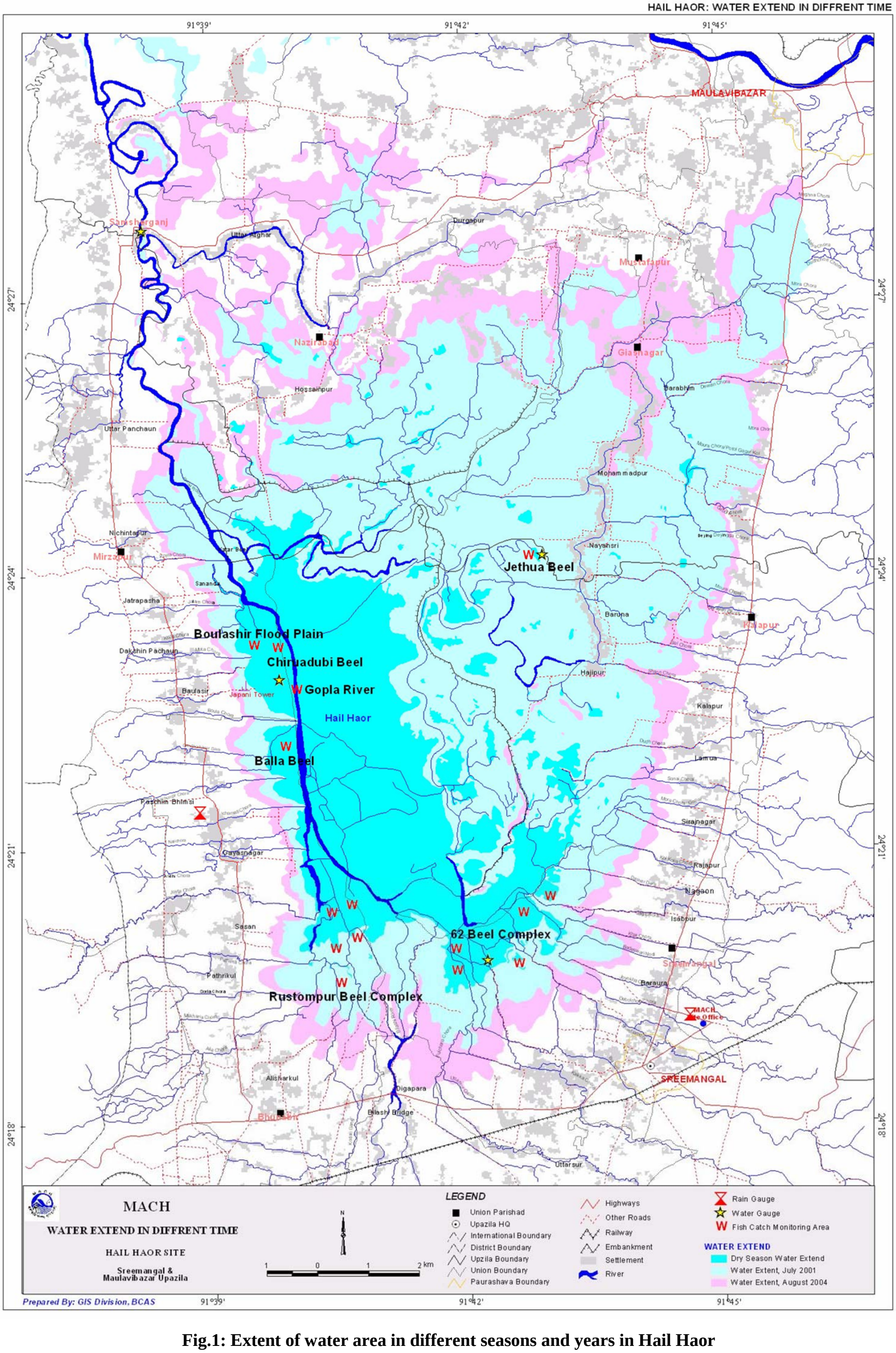

Fig.1: Extent of water area in different seasons and years in Hail Haor

4. Interventions under the MACH Project

With the objectives of achieving sustainable management of Hail Haor wetland and its fishery for food security, a number of development and management interventions have been taken in the haor under the MACH project since 2000 (see Table 2):

- (i) Raising awareness and motivation the community about the need for wetland and fisheries management including limits on fishing and exploitation,
- (ii) Fish habit improvement through excavation,
- (iii) Establishment of fish sanctuaries,
- (iv) Re-stocking of locally rare or extinct fish species,
- (v) Reducing fishing pressure by helping poor fishers diversify livelihoods and change occupation through credit and training,
- (vi) Seasonal closure of fishing,
- (vii) Planting wetland trees, and
- (viii) Reducing siltation through soil conservation and better land-use management in the surrounding hills.

Table 2 : Fishery management interventions in Hail Haor under MACH.

Intervention	1999 (Base year)	2000	2001	2002	2003	2004	2005
Awareness raising on sustainable fisheries management (approx No. of people covered)	10,000	25,000	57,000	115,000	109,000	54,000	130,000
Fish habitat improvement (area excavated) (a) Beel (ha) (b) Canal (meter)	 1.25 -	 3.63 -	 4.69 3,576	 1.98 3,220	 2.37 4,406	 0.02 -	 6.08 -
Establishment of sanctuaries: area in ha (number in parenthesis)		6.00 (16)	1.00 (8)	9.04 (2)	-	40.68* (1)	-
Restocking of locally rare fish species (No. of fingerlings)		19,828	36,097	1,76,845	3,63893	1,76,806	-
Seasonal closure of fishery (area and period)				70.48 ha	149.30 ha	930.72 ha	
				2-3 months during April-June			
Wetland plantation (No. of trees planted)	32,604	9,807	15,242	17,292	38,013	25,874	3,000

* Permanent sanctuary

5. Methodology

5.1 Data collection

To assess the impact of the project activities (interventions) and dynamics of hydrology on fish production a monitoring program was undertaken. The monitoring program included hydrological monitoring of water depth, a study on siltation, monitoring of rainfall; and fish catch monitoring in the haor. Both fish catch monitoring and hydrological monitoring started from April 1999.

For the purpose of this paper fish catch monitoring data and hydrological monitoring data have been used. The methodologies of data collection and analysis are described below. The first year's data from 1999 are treated as base line information in the analysis.

5.1.1 Catch monitoring system and production estimates

To assess changes in fish production – Catch Per Unit Area (CPUA), Catch Per Unit Effort (CPUE) and fish biodiversity was monitored in the haor. To represent the haor habitats, data was collected from seven sampling stations with defined habitats covering the river, canals, beels and floodplains in different parts of the haor as shown in Table 3 and Fig. 1.

Table 3: Monitoring locations, habitats and areas in Hail Haor

Monitoring locations	Monitoring area (ha)	Habitat types
Jethua Beel (1)	67.95	Beel, canal, floodplain
Gopla River	41.23	River
Boulashir floodplain	234.38	Floodplain
Chinuadubi	30.40	Beel
62-Beel complex	419.48	Beel, floodplain
Rustompur beel complex	221.73	Beel, canal, floodplain
Balla Beel	159.09	Beel, floodplain
Total	**1174.26**	

From each sampling station species-wise catch (by number and weight) were recorded using a fixed format for a sample of fishing gears. For each type of gear at least 10% of a particular gear in operation on the sampling day were monitored provided at least three units of that gear were found working, or all units in operation up to three were monitored. To accommodate any temporal variations in a month, the sampling was undertaken for one complete day (twenty four hours) every 10 days in each sample station, and continued throughout each year. On the basis of the fish catch monitoring, species-wise fish catch, overall CPUA and CPUE, and number of species have been estimated for the monitoring areas and for the haor as a whole during the project period by month and year.

5.1.2 Hydrological Information

Water levels have been recorded on a daily basis at four locations in the haor (Fig.1). Siltation in 22 charas was also measured and recorded by using silt traps at different locations. Annual sediment load of charas flowing into Hail-Haor has been estimated at around 100,000 tons and the rate of siltation of the haor is about 5 cm annually. Rainfall data have been recorded at two stations (Cheroadobi in the haor and MACH office at Sreemangal (Fig. 1). From the available depth contour data of the haor and the water level records, the surface water area of the haor in different months has been estimated using a digital elevation model (Table 4). The changes of water extent (area) in different months of 2004 are shown in Annex 1.

Table 4 : Inundated area (ha) of Hail Haor

Month	1999	2000	2001	2002	2003	2004	2005
January	***4,835***	4,835	4,695	4,780	5,140	5,132	**5,300**
February	***4,488***	4,488	4,415	4,362	4,705	4,733	**5,554**
March	***4,687***	4,687	3,741	3,474	3,762	3,795	**4,853**
April	5,215	4,164	3,501	4,558	4,523	**9,330**	5,107
May	8,263	6,782	7,192	9,776	7,544	**10,021**	
June	12,031	12,214	12,215	**13,516**	11,186	11,023	
July	12,581	10,910	10,850	**13,995**	13,490	13,658	
August	13,288	11,707	11,698	14,926	12,273	**15,835**	
September	12,162	11,634	11,563	12,958	11,058	**13,508**	
October	11,694	11,907	11,931	11,396	11,132	**12,102**	
November	9,738	**10,346**	10,274	9,445	9,859	8,755	
December	7,744	7,245	7,200	7,323	**9,166**	7,788	

Bold = for each month the year with highest area of inundation recorded
Italics = data not recorded in 1999, so the 2000 figures are assumed to have applied

5.2 Data analysis

Attempts have been made to see if the fish production of the Haor is dependent on the following parameters related to the hydrological regime of the Haor:

(i) Date of commencement of pre-monsoon flooding (April-May).
(ii) Maximum inundation, extent and period.
(iii) Minimum inundation extent and period.
(iv) Average inundation during April-May (Breeding season of fish).

(v) Total annual inundation area in terms of total ha-days of water, that is the sum of daily water area (area prevailing on each day in the year):

$$y = \sum_{i}^{365} x_i$$ where y = total inundation area of a year, x = daily inundation area

In analyzing the fish production in relation to hydrological regimes of the Haor, two different scenarios were applied in respect of annual hydrological cycles.

As both fish catch and hydrological monitoring started from April 1999, initially the period from April of one calendar year to March of the next calendar year was considered as a year for the purpose of comparison with fish production. Thus, the period from April 1999 to March 2000 was taken as the base year and the corresponding one year period (April-March) of the next years has been considered in defining each of the "impact years".

On further scrutiny, some anomalies were observed in respect of hydrological regime and production analysis using this approach. The dry season is usually from January to April and sometimes extends up to May. Retention of dry season water is very important for successful breeding of fishes in April-May and consequently fish catches and production in the remainder of the year. If the production year is considered from April to March, then the impact of the full dry season of the year is not reflected in the production of that 12 month period. On the other hand if the calendar year (January-December) is considered as a production year, then the full dry season is reflected in the production of the same 12 month period. So an alternate analysis was undertaken using the calendar year as the production year.

Therefore, two scenarios of hydrological regime - (1) taking April-March as a production year and (2) taking January-December (calendar year) as a production year - have been considered to see the hydrological impact on fish production. As both hydrological and fish production data are available from April 1999, the base year has been considered from April 1999-March 2000 under scenario-I. The base year under scenario-II is from January to December 1999, but three month's data (January-March 1999) are not available. To make the two scenarios comparable, the data of the corresponding months (January to March) of the next year 2000 have been used for 1999.

Table 5: Inundation and CPUA under scenario-I.

Year (April-March)	Total annual inundation in ha/days (in 1,000 ha)	CPUA (kg/ha)
1999-00	3,245	171
2000-01	3,041	205
2001-02	3,022	191
2002-03	3,402	287
2003-04	3,170	161
2004-05	3,590	387

Table 6: Inundation and CPUA under scenario-II.

Year (January-December)	Total annual inundation in ha/days (in 1,000 ha)	CPUA (kg/ha)
1999	3,245	171
2000	3,076	144
2001	3,029	183
2002	3,372	254
2003	3,168	207
2004	3,529	307

The catches of the months from January to March 2000 are the lowest of all the years under consideration. Inundation area during January-March 2000 was moderate. Therefore the estimates of catch and water area for 1999 in total are little affected by including estimates for January-March based on the following year, and it is thought that the 2000 dry season was comparable to the 1999 dry season.. On this basis fish production (CPUA) for calendar year 1999 has been estimated. Estimated total annual inundation and annual fish production (CPUA) under scenarios-I and II are shown in Tables 5 and 6.

6. Results

6.1 Commencement of pre-monsoon flooding and production

Out of the four sampling stations for water level recording, the water levels of one centrally located station – Cheruadubi Beel - are shown in Fig. 2 for 1999-2004 (scenario-II). As noted above January-April water levels for 1999 are not available but are thought not to have been outside the range of the other years.

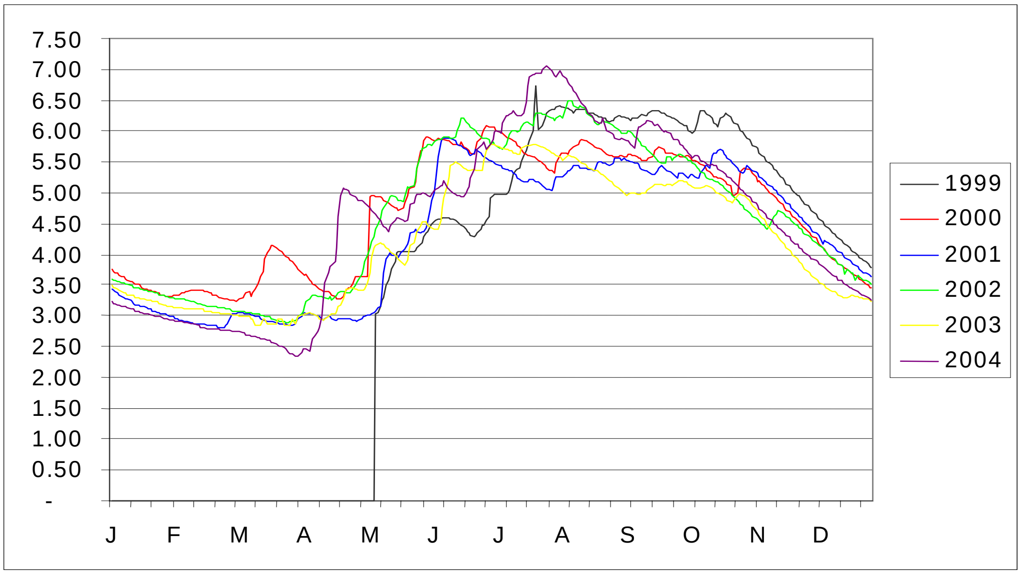

Figure 2: Water levels in Hail Haor in different months and years.

Fig. 2 shows that during 1999 the water level up to June was less than that of any other year under study but in the post monsoon period, the water level was much higher than in any other year and the maximum water level also was high (second highest for this site). Water level was higher in the dry season of 2000 because there was more rainfall during that period than in other years (Fig. 3) and the water level was above 5.5 meters for longer (130 days, Table 7) in 2000, although the post monsoon water level was moderate.

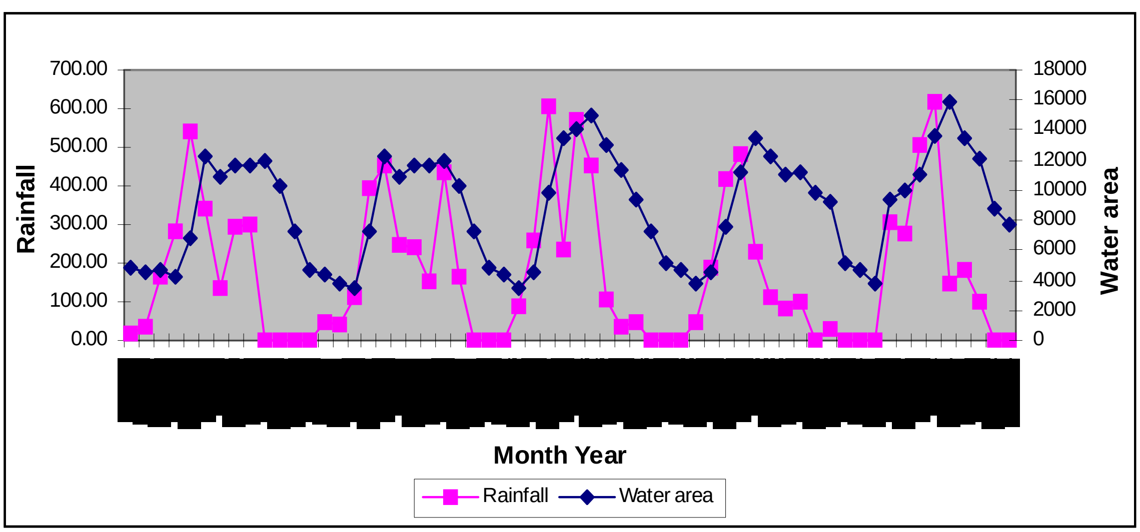

Fig. 3: Water area and rainfall by month and year

Table 7: Duration of inundation at different water levels (meters – m above PWD in Hail Haor)

Year	Period of inundation at different water levels (days)												
	1 m	1.5 m	2.0 m	2.5 m	3 m	3.5 m	4 m	4.5 m	5 m	5.5 m	6 m	6.5 m	7 m
1999					365	360	210	193	150	120	100	5	0
2000					365	291	250	210	160	130	10	0	0
2001				365	315	235	210	183	160	35	0	0	0
2002				365	340	255	225	195	155	130	50	3	0
2003				365	345	225	205	153	140	50	0	0	0
2004				350	285	255	225	214	155	110	50	30	5
Water area for each water level		480	1,830	3,180	4,529	5,879	7,228	8,578	9,927	11,277	12,627	13,976	15,326

Interpretation: in 1999 the water level was always at 3 m or more above datum, 4,529 ha of the haor was inundated for 365 days, the water level reached a maximum of 6.5 m above datum and this inundated 13,976 ha for just 5 days.

The water level in 2001 was moderate and low water levels continued until the end of April, but there was a very early flood peak. In 2002, water level receded slowly until the end of March, and began to increase from early April. The water retention period above 5.5 meters was longest during 2002 (130 days, Table 7). The year 2003 was also a moderate flood year and the highest water level was below 6 meters and the post monsoon water levels were less than those of all the other years under consideration. The dry season water level during 2004 was the lowest of those recorded, but there was an early rise in water level and the monsoon water level was the highest among all the years.

From the 6 years of hydrological data, it is observed that the water level of Hail Haor is lowest in March-April and begins to rise in April-May (Fig. 2). The date of pre-monsoon flood commencement appears to be a factor impacting yearly fish production as this is the fish breeding time. The earlier the flood-water level rises in April, the more breeding that is likely to take place and the more production might be expected if other conditions remain unchanged.

Table 8 shows the commencement dates of pre-monsoon flooding and the CPUA in different years under the above mentioned two scenarios.

Table 8: Commencement of pre-monsoon flooding in Hail Haor.

Production Year			Start of flooding	Duration of minimum dry season water level (3 m or less water level at Cheruadubi beel)	Production (CPUA)(kg/ha)	
Impact year	Scenario-I (Apr-Mar)	Scenario-II (Jan-Dec)			Scenario-I	Scenario-II
Base year	1999-00	1999	5 May 1999		171	171
Impact-I	2000-01	2000	21 April 2000	Always above 3 m and rising from mid-March	205	144
Impact-II	2001-02	2001	2 May 2001	1 February to 30 April with rise in 1st week of March and 1st week of April	191	183
Impact-III	2002-03	2002	1 April 2002	15 March to 31 March	287	254
Impact-IV	2003-04	2003	15 April 2003	1 March to 15 April with rise in 1st week of April	161	207
Impact-V	2004-05	2004	6 April 2004	1 February to 5 April	387	307

In both the scenarios the commencement of pre-monsoon flooding was of course on the same date but the CPUA patterns are different since scenario I includes the dry season just before the onset of pre-monsoon flooding, while scenario II includes the following dry season almost a year later. From the analysis it appears that pre-monsoon flood onsets in the first three years were in the last week of April and first week of May. But since 2002 there have been three years of earlier pre-monsoon flooding with two years starting in the first week of April and 2003 from 15 April. Fish catch (CPUA) in those years with early onset of pre-monsoon flood were much higher (287 or 254 kg/ha in 2002-03 or 2002; and 387 or 307 kg/ha in 2004-05 or 2004) than those of the other four years (Table 8).

In scenario-I, the CPUA of 2000-01 (impact year-I) was higher than in the baseline year, and the onset of rising water that year was about 20 days earlier than the base year, but in scenario-II, with the same flooding pattern and higher level of water in dry season, the CPUA in the impact year-I (2000) was the lowest of all years including the base year (catches in January-April 2000 were lower than in the same months of 2001), although flooding started from two seeks earlier than the previous year. However the maximum inundation and post monsoon inundation during 2000 (impact year-I) were lower than those in 1999. These two factors may be partly responsible for low production in 2000.

Again in scenario-I, the CPUA (161 kg/ha) of impact year IV (2003-04) with early flooding commencing more than 3 weeks before that of the base year (1999-00) and impact year II (2001-02) was the lowest of all studied years and even less than in the base year (1999-00). During this year the low yields have been attributed to reduced fishing intensity due to excessive coverage of aquatic weeds in the haor. The fishing intensity (number of gear units operated per day) of the important gears operated in sampling location was less during this year, although CPUE was more or less the same(Table 9), which has contributed to low CPUA in that year. The protection offered by the aquatic vegetation likely meant that the fish were not able to be harvested. This could have been a factor in the resulting low yield during the year of the vegetation and a factor in the resulting high yield the following year. Under scenario-II, the CPUA of impact year IV was higher than that of the base year and impact years-I and II, suggesting overall that the method used in scenario II gives a fairer picture of relations between fish catches and flooding patterns.

Table 9: Fishing intensity and Catch Per Unit Effort (CPUE)

Gear	No. of gears operated per day and CPUE* in different years (kg)					
	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05
Bhesal (large lift net)	5.8 (5.3)	8.16 (7.39)	10.92 (4.91)	5.81 (6.37)	2.53 (6.34)	9.71 (7.78)
Ber jal (seine net)	6.26 (6.87)	8.71 (11.70)	1.22 (7.54)	5.38 (9.55)	1.49 (9.30)	7.87 (20.77)
Current jal (gill net)	881 (0.18)	488 (0.15)	669 (0.25)	792 (0.20)	440 (0.17)	906 (0.21)
Suta jal (Filtering net)	233 (0.17)	32 (0.18	218 (0.28)	199 (0.10)	88 (0.24)	66 (0.25)
Traps	383 (0.06)	546 (0.12)	749 (0.10)	723 (2.70)	999 (0.07)	1157 (0.24)
Thela jal (push net)	22.74 (1.31)	6.34 (2.26)	14.80 (2.88)	7.15 (2.70)	9.66 (2.89)	4.91 (3.33)

* CPUE in parentheses

Although flooding started only one week earlier in 2003 (15 April) than that in 2000 (21 April), in scenario-II the CPUA in 2003 (207 kg/ha) was much higher than that of 2000 (144 kg/ha). The CPUA during 2003 (impact year IV) was much less than that of 2002 and 2004, probably due to the late start of flood in 2003 (15 April) compared to 2002 and 2004 (1 April and 6 April respectively) and it may be partly due to reduced fishing effort as mentioned above. Higher production in 2002 and 2004 was probably due partly to the increased vegetation the year before, to the earlier onset of pre-monsoon flooding and specific interventions by the communities.

CPUA showed a reasonably strong correlation with date of commencement of pre-monsoon flooding in relation to 1st April (days from 1 April onward when pre-monsoon flood commenced) ($R^2 = 0.51$ for scenario I and $R^2 = 0.58$ for scenario II) supporting the above findings that the earlier the commencement of flood the higher the fish production (Fig. 4a and 4b).

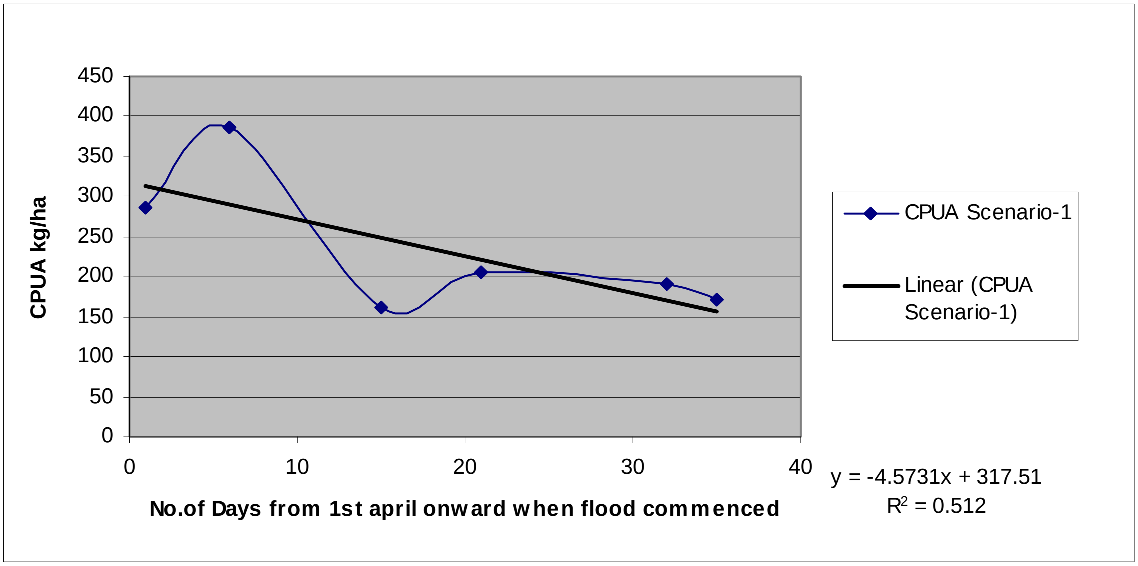

Fig. 4a: Commencement Dates of Flooding and CPUA (scenario I)

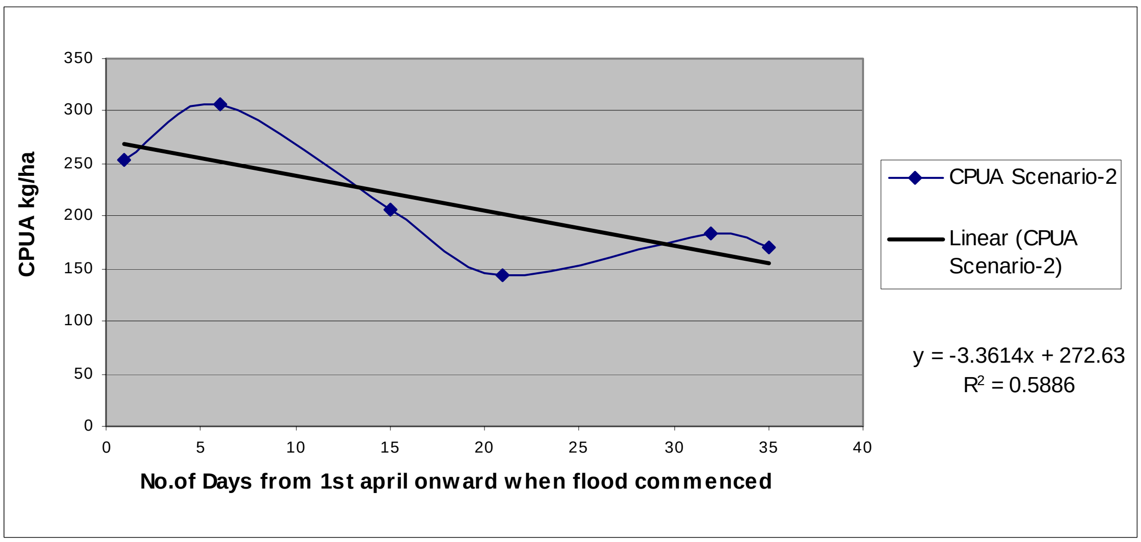

Fig. 4b: Commencement Dates of Flooding and CPUA (scenario II)

Although not all years conform to the expected pattern, depending on the scenario, the evidence indicates that an early start to monsoon flooding during April has an overall positive impact on fish production. Therefore, in Hail Haor April-May be considered a critical period for fish production, that is, the earlier the flood comes, the higher would be the fish production. However, higher production is not solely due to earlier inundation but also is expected to be influenced by a combination of other hydrological parameters (maximum inundation area and duration of inundation) and the management interventions taken under the MACH project. Other factors affecting the catch such as heavy growth of aquatic vegetation could have a beneficial impact on the following years catch.

6.2 Extent and duration of flooding and fish production

The extent and duration of inundation in terms of total annual water area in hectare-days, monthly maximum wet season water area, monthly minimum dry season water area, and monthly average water area during April-May for different production years along with CPUA under scenarios I & II are shown in Tables 10 and 11. Bivariate analysis of hydrological parameters (independent variables) with fish production (CPUA) as dependent variable has been done. The regression coefficients are also shown in Tables 10 and 11.

Table 10 : Extent of inundation and fish production (Scenario-I).

Year	Total annual inundation (ha-days)	Maximum water area (ha)	Minimum water area (ha)	April-May average water area (ha)	Annual fish production CPUA (kg/ha)
1999-00	3,245,104	13,288	3,925	6,769	171
2000-01	3,040,952	*12,214*	3,741	5,473	205
2001-02	*3,022,301*	12,215	*3,471*	*5,347*	191
2002-03	3,401,908	14,926	3,762	7,167	287
2003-04	3,170,096	13,490	3,795	6,034	*161*
2004-05	**3,590,259**	**15,835**	**4,853**	**9,676**	**387**
Regression with CPUA	R = 0.857 R^2 = 0.734	R = 0.864 R^2 = 0.747	R = 0.803 R^2 = 0.646	R = 0.947 R^2 = 0.897	

Highest year in bold, lowest in italics

Table 11 : Extent of inundation and fish production (Scenario-II).

Year	Total annual inundation (ha-days)	Maximum water area (ha)	Minimum water area (ha)	April-May average water area (ha)	Annual fish production CPUA (kg/ha)
1999	3,245,104	13,288	**4,488**	6,769	171
2000	3,076,667	*12,214*	4,164	*5,347*	*144*
2001	*3,029,427*	12,215	3,501	5,473	183
2002	3,372,216	14,926	*3,474*	6,034	254
2003	3,168,537	13,490	3,762	7,167	208
2004	**3,529,265**	**15,835**	3,795	**9,676**	**307**
Regression with CPUA	R = 0.952 R^2 = 0.906	R = 0.970 R^2 = 0.941	R = 0.396 R^2 = 0.157	R = 0.940 R^2 = 0.883	

Highest year in bold, lowest in italics

Bivariate regression of maximum inundation (maximum monthly average water area) and CPUA shows a high correlation (R = 0.970, R^2 = 0.941) in scenario-II (Fig. 5b), this indicates that 94% of variation of CPUA can be explained by the maximum inundation area. While under scenario 1 (Fig. 5a), 74% variation of CPUA is explained by maximum inundation (R = 0.864, R^2 = 0.747).

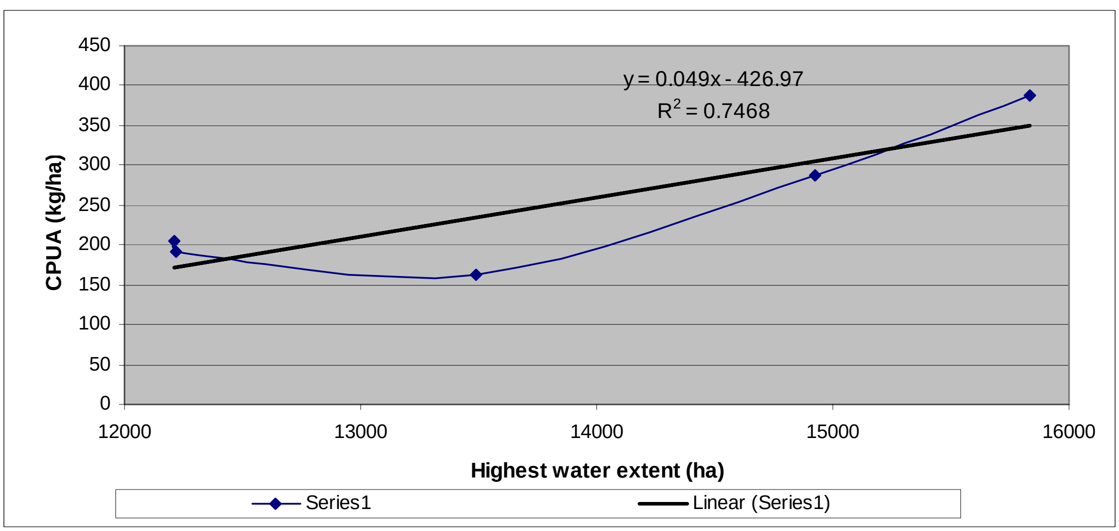

Fig. 5a: Highest water extent vs. CPUA in scenario I

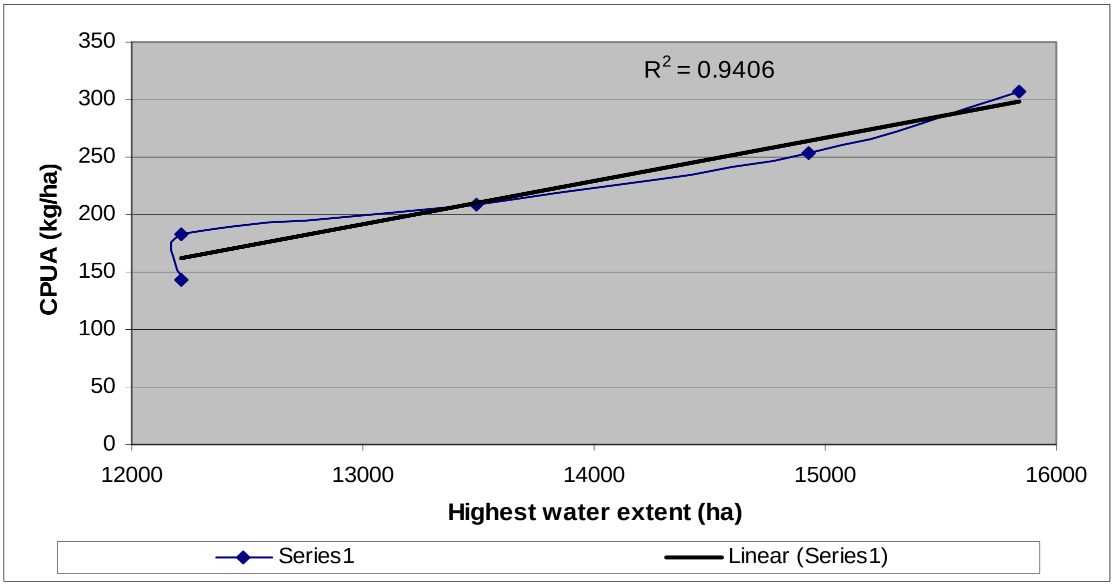

Fig. 5b: Highest water extent vs. CPUA in scenario II

Bivariate regression analysis of total annual inundation (in hectare-days) and CPUA under scenario-II (Fig. 6b), also shows a high correlation (R = 0.952 or R^2 = 0.906) – i.e. 90% of variation in CPUA can be explained by the total annual inundation (hectare-days). In scenario-I (Fig. 6a) the equivalent correlation is marginally significant (R = 0.857, R^2 = 0.734).

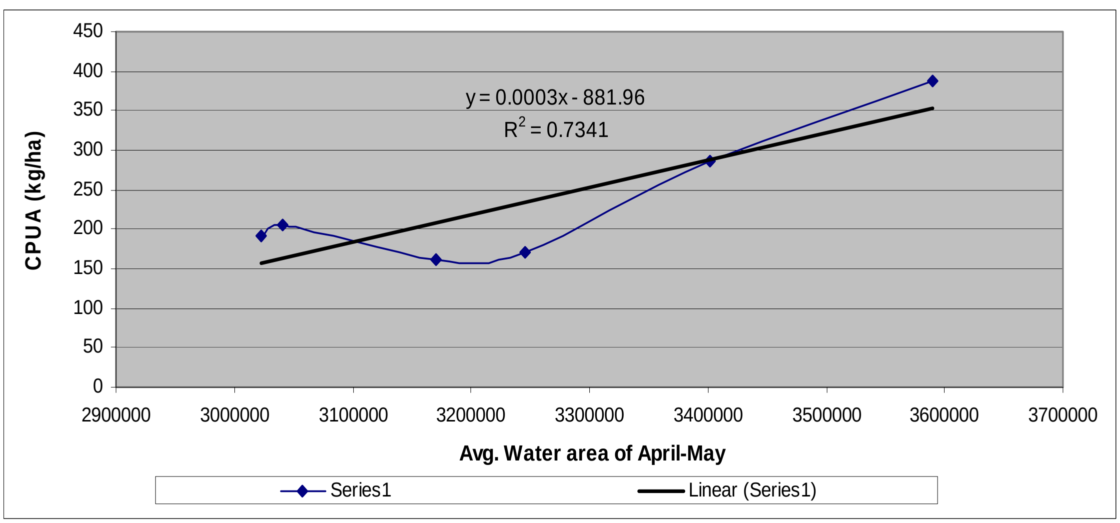

Fig. 6a: Total Annual Inundation (hectare-days) vs. CPUA (kg/ha) in scenario I

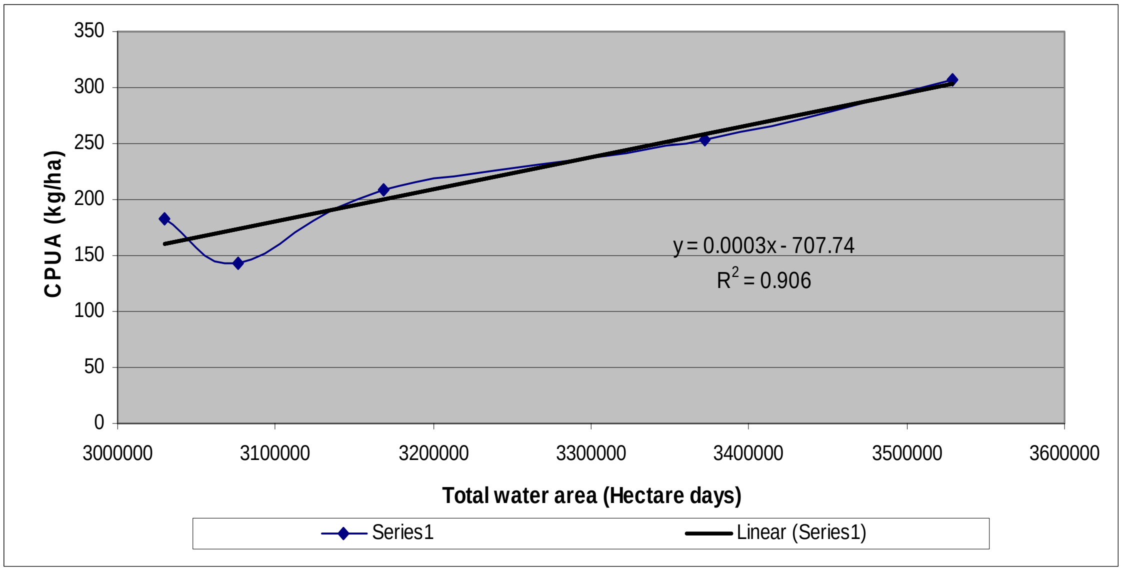

Fig. 6b: Total water area (ha-days) vs. CPUA (kg/ha) in scenario II

But under scenario II (Fig. 7b), the regression analysis of minimum monthly dry season inundation with CPUA does not show any significant correlation (R = 0.396 or R^2 = 0.157) though under scenario I it is marginally significant at 0.05 level (R = 0.804, R^2 = 0.646). Minimum dry season inundation could be a proxy indicator for the success of spawning of the beel fishes and consequently influence their production. However, the data indicates that the annual minimum inundation area that existed in the haor during the period from 2000-2004 did not have much influence on the variation of the CPUA, that is, the minimum inundation of around 3,000 ha is sufficient to sustain the range of fish production recorded in this period in the haor. This could be a result of the digital elevation model (DEM) not being useful at low levels whereas it does reasonably model the higher water levels. The DEM is not as accurate at modeling the low water levels as it is the higher.

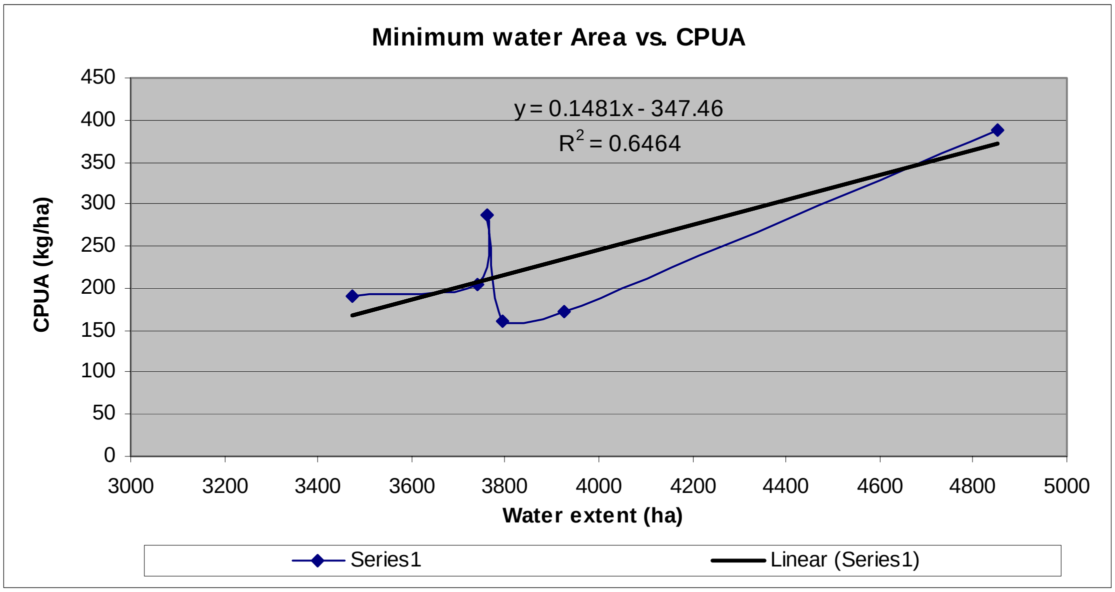

Fig. 7a: Minimum water area vs. CPUA in scenario-1

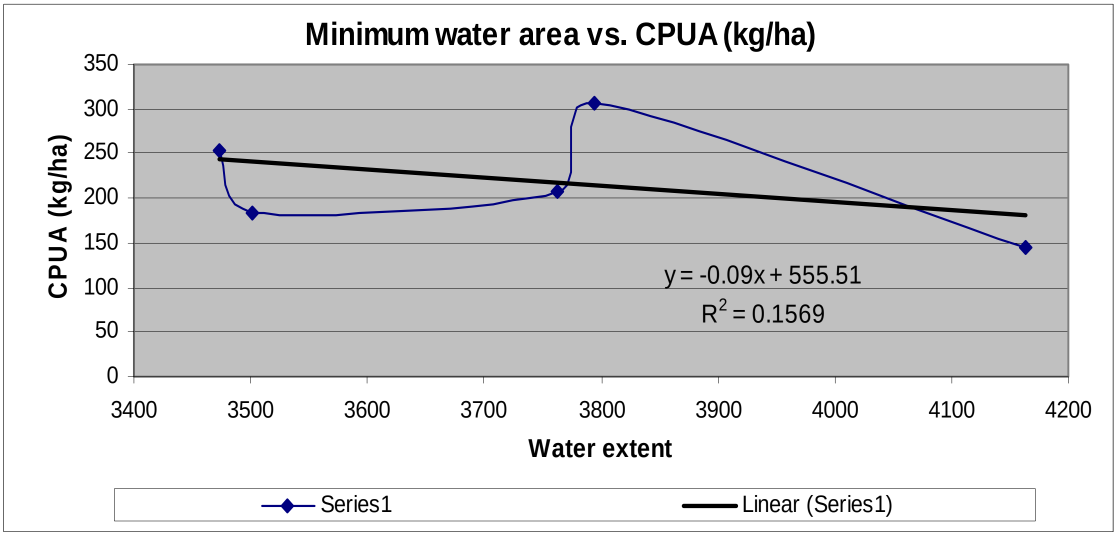

Fig. 7b: Minimum water area vs. CPUA (kg/ha) in scenario-II

On the other hand, the April-May inundation area under scenario I (Fig. 8a) and scenario II (Fig. 8b) was significantly correlated with CPUA (R = 0.947, R^2 = 0.897; and R = 0.940, R^2 = 0.883 respectively). April-May is the peak spawning season and so retention of more water in the haor during this period favors successful breeding and survival of larvae/ fry that ultimately influence the fish production.

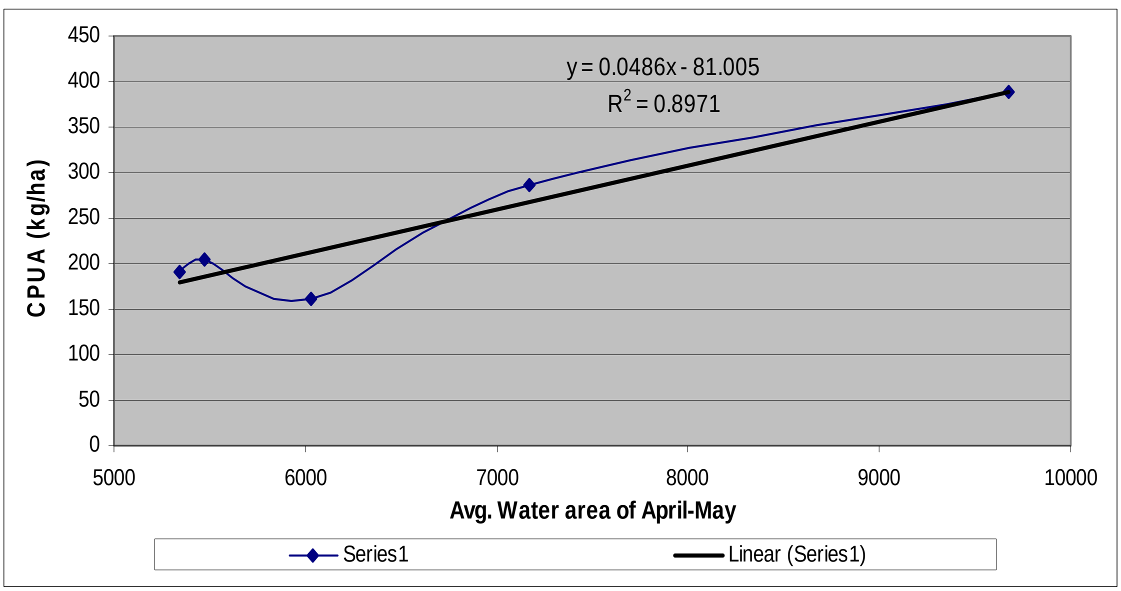

Fig. 8a: April-May avg. water area vs. CPUA (kg/ha)

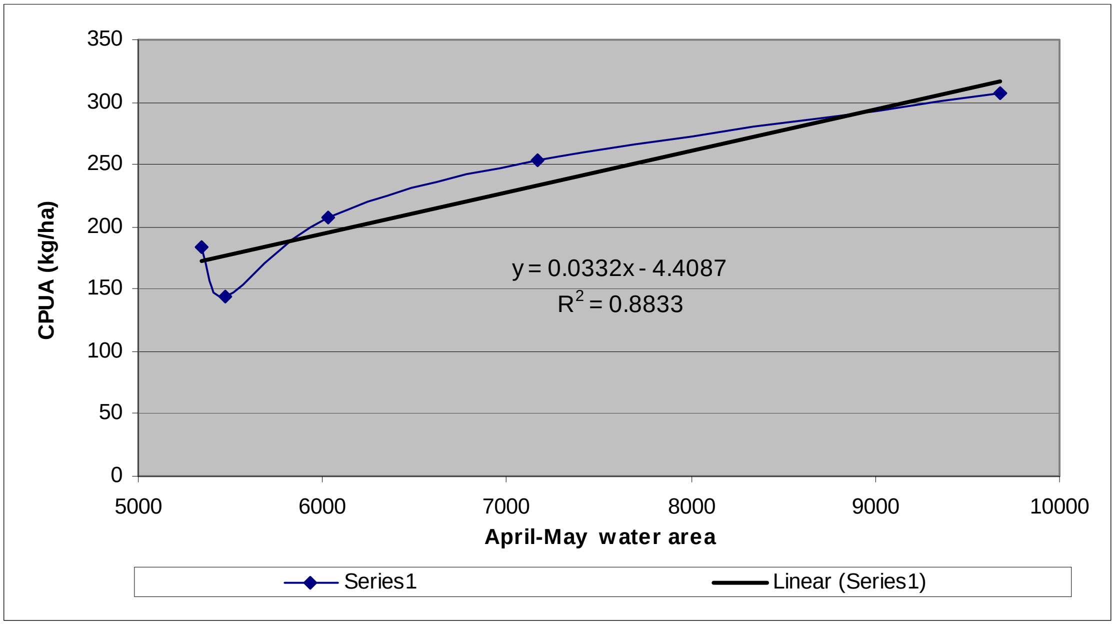

Fig. 8b: April-May water area vs. CPUA (kg/ha)

7. Discussion

The general hypothesis is that the greater the surface area and duration of inundation in a water body, the greater is the aquatic production, provided that all other conditions such as spawning success / recruitment, availability of food, water quality, fishing intensity, etc. remain the same. The present study on the extent and duration of inundation and its relation with fish production in Hail Haor generally supports the above hypothesis. The study has shown that the early commencement of pre-monsoon flooding, extent of water area in spawning season (April-May), total annual inundation period (in hectare-days) including highest water level/area have an effect on fish production (CPUA) in the anticipated directions, of course with some exceptions and deviations due to the reasons mentioned above.

The management interventions of the MACH project are believed to have had a positive impact on fish production of the haor (Ali and Thompson 2006; MACH 2003b). This is evidenced when under more or less the same hydrological conditions, fish production in 2000 and 2001 (Scenarios I and II) and in 2003 (Scenario II) with intensification of interventions, have been found to increase compared to baseline production (Tables 2, 10 and 11) when there was no intervention. However, those years with earlier onset of flooding and greater volumes of flooding tended to be in the later years of the study when also there had been a longer period of interventions. It is likely that the fish production of the haor has been influenced by a combined effect of the hydrological regime and the improved fishery management linked with MACH. Vegetation also plays a role and is likely a restriction to catch yields but could be providing a periodic boost to the following years yields.

Lastly, with only six years of data it is clear that the trend in production from Hail Haor is upward when looking at the total years that were higher that the baseline. This has also been verified through the consumption study which has also shown an upward trend from an entirely different data set.

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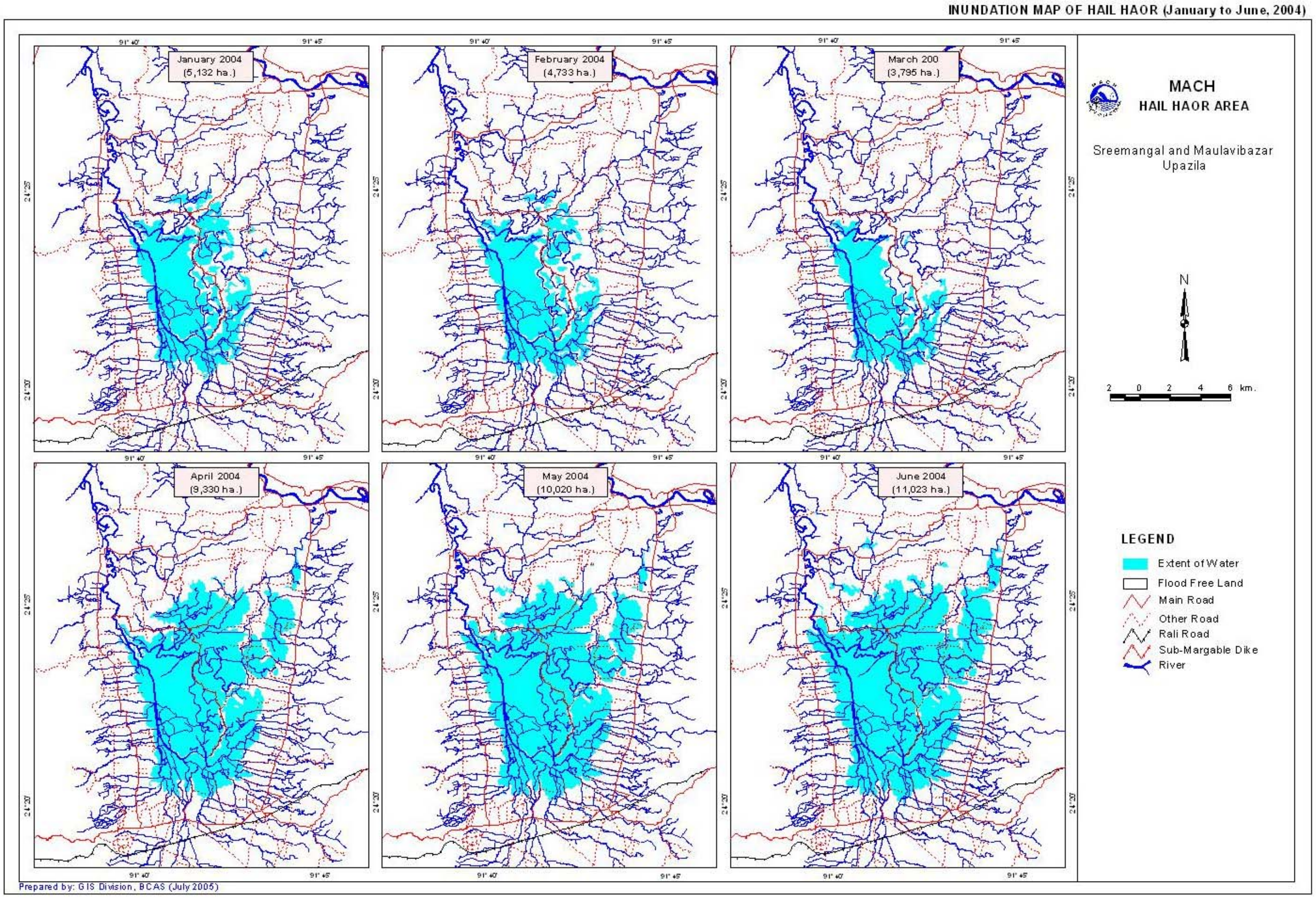
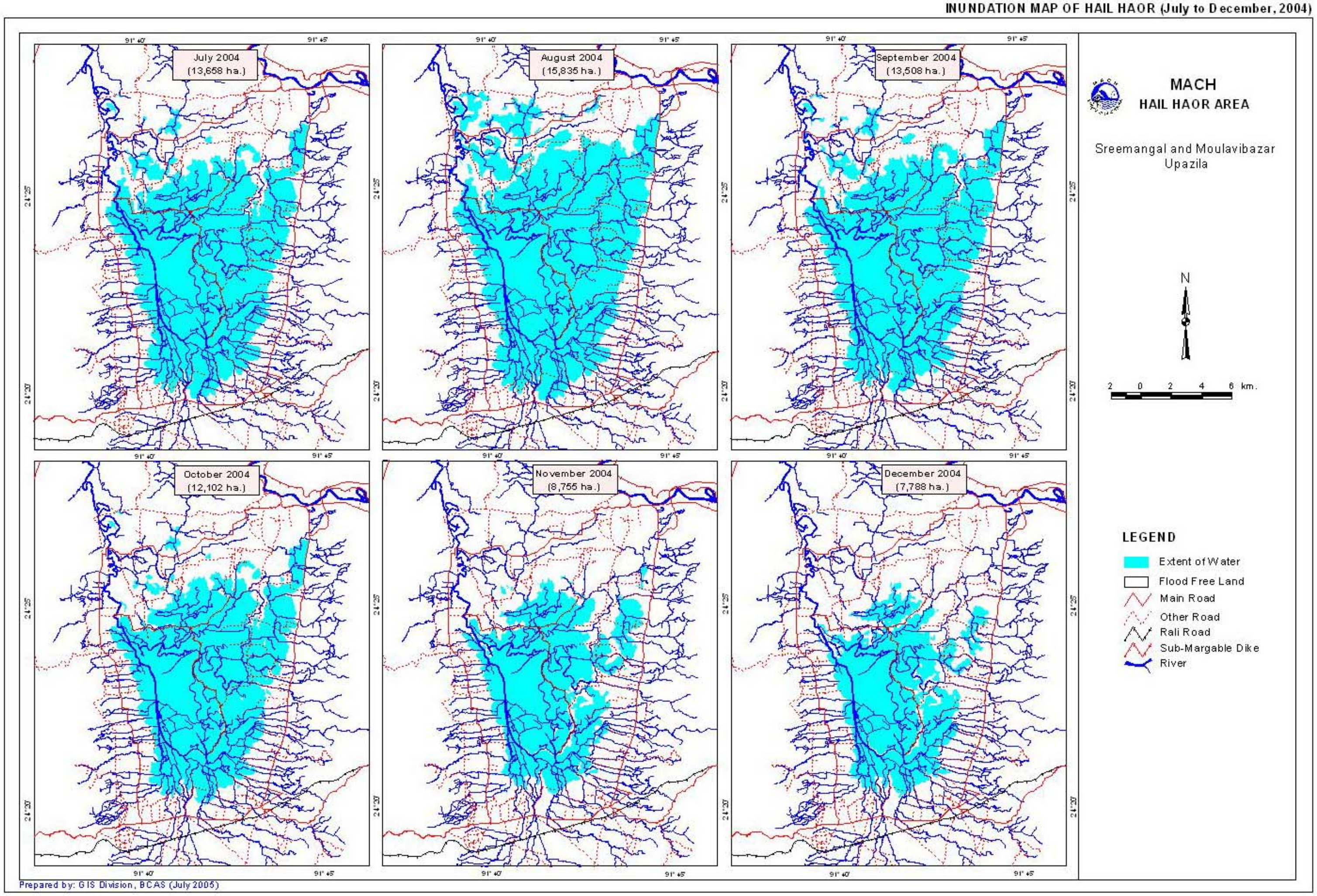
Annex: Inundation Maps of Hail Haor (January to December, 2004)



INUNDATION MAP OF HAIL HAOR (July to December, 2004)



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