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Geoinformatics based Waterlogged Area Delineation for Water Chestnut and Aquaculture Cultivation in Eastern India and its Economics

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Adoption of conventional agriculture in waterlogged areas always remains a challenge mainly due to changed physical, chemical and microbiological properties of waterlogged soils. Even with such limitation, cultivation of economically important aquatic food crops like water chestnut/makhana and their integration with aquaculture is a lucrative option in improving the rural economy in waterlogged areas. In this study, geo-referenced LISS III data (1:50000 scale) was used to delineate the waterlogged areas to make such interventions with aquaculture in the coastal and its adjoining areas of Odisha. The existing impact of water chestnut on production performance of catfish appeared promising. Case studies show that these interventions resulted in a yield of 11 t ha^{-1} of water chestnut and 0.47 t ha^{-1} of catfish. The gross water productivity of aquaculture alone was ₹ 7.90 m^{-3} which could be enhanced further to ₹ 16.30 m^{-3} through integrated cultivation of water chestnut with catfish. Identification and delineation of suitable waterlogged areas for integrated water chestnut and fish cultivation using remote sensing and GIS tools would help in upscaling this cultivation system so as to improve the socio-economic livelihood of the farming community.

(***Key words:*** *Aquaculture, Eastern India, GIS, Remote sensing, Waterlogging, Water chestnut*)

Judicious utilization of challenged ecosystems is highly essential to ensure the food security objectives of India. This holds more relevance when the net cultivated area has remained almost stagnant for the last few decades while we are experiencing a phenomenal difference in population growth rates and food grain production. Waterlogged ecosystem is one such challenged ecosystem which needs to be addressed with multipronged technological and policy solutions. In India, out of the 140 million ha (Mha) net sown area, about 11.6 Mha (8.3%) is affected due to the problem of waterlogging that remains sub-productive (Planning Commission, 2011). The Ganga-Meghna-Brahmaputra (GMB) basin has fertile lands, with high population density and houses about 500 million of the world's poorest people (Shah, 2001). Eastern India, comprising mainly the 15 eastern districts of Uttar Pradesh and the entire states of Bihar, West Bengal and parts of Odisha, constitute a significant portion of the GMB basin. The region is marked by high dependence of its predominantly rural population on smallholder agriculture and wage-labour. Because of its vulnerability to submergence and flood, waterlogged area in this area suffers from uncertainties of productivity.

The first option to utilize such lands is the cultivation of economically important aquatic plants having natural adaptation capability (Ambast, 2015). In addition to rice, there are several commercially important food and non-food crops like water chestnut (Roy Chowdhury *et al*., 2003, 2004) or water chestnut integrated with aquaculture (Brahmanand *et al*., 2015), cat-tail or *Typha spp*. (Roy Chowdhury *et al*., 2017), lotus - *Nelumbo nucifera* (Puste, 2003, Mondal *et al*., 2007), hat plant / shola - *Aeschynomene aspera* (Poddar and Roy Poddar, 2012) which are cultivated exclusively in waterlogged areas. As the depth and duration of submergence plays a vital role in successful establishment and yield enhancement of such crops, there is an urgent need to identify the possible scenarios for successful crop management. The integrated water chestnut and pisciculture technology has already significantly improved livelihood of the farmers in waterlogged areas (Ghosh *et al*., 2011). In this context, identification of potential areas suitable for such integrated activity with the help of remote sensing and GIS (Nayak *et al*., 2018) paves a better way to increase water productivity of such ecologically challenged ecosystem. In this paper, we attempted to delineate such areas with immense potential for cultivation of water

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chestnut and aquaculture. The performance assessment of water chestnut-aquaculture in such a delineated area in Balasore district of Odisha, India is also presented in this paper.

MATERIALS AND METHODS

About the study area

The study was conducted in Balasore district of Odisha. The district is located between 21° 03′ to 21° 59′ N latitude and 86° 16′ to 87° 29′ E longitude. The area is having an average elevation of 28.3 m above mean sea level. The area falls under Agro Ecological Sub Region: Gangetic Delta, hot moist, sub-humid eco-sub region (18.5) and receives average annual rainfall of 1701 mm while 1481 mm during south-west monsoon (June-September). Predominantly soils are alluvial (CRIDA, 2011). Balasore district is crisscrossed with perennial and estuarine rivers because of its proximity to the sea. Two important rivers of Odisha, the Budhabalanga and Subarnarekha, pass through this district from west to east before flowing into the Bay of Bengal. Field observations such as water spread, water depth, quality of water for determining suitability of water bodies for undertaking aquaculture and water chestnut were taken in Haldipada gram panchayat (21° 34′ 30″ N, 87° 0′ 06″ E) in Balasore district of Odisha, India. The Haldipada area is having an average elevation of 8.0 m above mean sea level with flat topography.

Geoinformatics application for waterlogged area analysis

To identify and map the waterlogged areas and to apply the remote sensing (RS) and geographical information system (GIS) approaches in the study area of Balasore district of Odisha, India, United States Geological Survey (USGS) Lands at 8 OLI-TIRS (Operational Land Imager - Thermal Infrared Sensor) imagery dated 08.05.2014 and 10.01.2015 were used. The Landsat 8 data was used in the study as data for any year including recent data is freely available and the developed procedure evolved from this study can be easily followed by other researchers/planners without spending money. The pre-monsoon data (08.05.2014) and post monsoon data (10.01.2015) were used to find out the locations where water is available in hot summer and in winter also, so that perennial water chestnut can be grown throughout the year. The Landsat 8 satellite payload consists of OLI and TIRS. These two sensors provide seasonal coverage of the global landmass at a spatial resolution of 30 meters (visible, near infrared, short wave infrared), 100 meters (thermal) and 15 meters (panchromatic). The image processing and GIS analysis was carried out using Arc GIS 10.5 and ERDAS Imagine Professional 2018 software. As the digital number (DN) values of each band of the satellite data of USGS Earth Resources Observation and Science (EROS) Centre does not give the reflectance values of each band, these were converted to TOA (Top of Atmosphere) Spectral Reflectance and then were corrected to TOA reflectance through radiometric calibration techniques. The projection type used here was Universal Transverse Mercator (UTM - Zone 45N), and the datum was WGS 1984. For delineation of the waterlogged areas suitable for integrated water chestnut - aquaculture intervention, the normalized difference water index (NDWI) was used (McFeeters, 1996) given by

$$NDWI = \frac{(X_{green} - X_{NIR})}{(X_{green} + X_{NIR})} \quad \text{... (1)}$$

where, X_{green} refers to the green band reflectance and X_{NIR} refers to the near infrared band reflectance.

This formulation of NDWI produces an image in which the ‘0’ and positive data values are typically open water areas; while the negative values are typically non-water features (*i.e.* terrestrial vegetation and bare soil dominated cover types). Like normalized difference vegetation index (NDVI), NDWI has a native scaling of -1 to +1. In the study area the NDWI ranged from -0.64 to 0.42. For delineation of the water features, values greater than 0 were marked as the water features. For mapping the water chestnut growing areas, the same signatures in NIR band was collected over the surveyed areas. The range of reflected values of NIR region of those areas were thresholded using the range 0.15 to 0.42, which is the reflectance of NIR region. NIR Spectral band operates in the best spectral region to distinguish vegetation varieties and conditions. Because water is a strong absorber of near infrared, this band has delineated water bodies (lakes and sinkholes), distinguished between dry and moist soils (barren land and croplands). So, in this way using the NDWI and NIR reflectance value the waterlogged areas and water chestnut plantation areas were delineated and also validated using National Remote Sensing Centre’s land use and land cover data. The remote sensing data of IRS-1D Linear Imaging Self Scanning Sensor (LISS III) with 1:50000 scale of the selected study area collected from Orissa Space Application Centre (ORSAC), Bhubaneswar was used in the present study. The base map of land use and land cover of the study area was collected from ORSAC for the year 2011 as they have used all the criteria of land use and land cover classification following guidelines as per NRSA (1995). Thematic map was prepared for the different types of water bodies present in the Balasore district, Odisha (Fig.1). Among them mainly three types of water bodies *viz*. inland natural wetlands, coastal natural wetlands and manmade wetlands categories were found suitable for fitting in integrated water chestnut-aquaculture cultivation intervention mainly because of suitable water regime. For water chestnut/aquaculture activities, a total area of 12473 ha was delineated for different waterbodies like perennial river/stream, perennials lakes/ponds, canals, reservoir/tanks as shown in Fig.1.

Crop management

The low-lying areas in Balasore district was identified as waterlogged area with at least 0.5 m water remained above surface at least for ten-month period over the year. In a representative waterlogged area in Haldipada block of Balasore district, the cultivation of water chestnut crop was taken up in a 3.4 ha area (Fig. 2). After extensive cleaning of aquatic weeds, land was ploughed during last week of May to first week of June 2015 before onset of monsoon. The organic manures, mainly decomposed oil cake and cow dung were incorporated @ 8 t ha^{-1} before planting during field preparation. Before planting, seedlings from nursery were given a combined treatment of fungicide and insecticide *i.e*. captan or carbendazim @ 0 .1% with chlorpyriphos @ 0.2% by dipping overnight (12 hours). Planting of water chestnut was normally carried out in second week of June. The young sprouting seedlings of 0.5 - 1.0 m length were planted depending on depth of water throughout the field. Three to four young seedlings were loosely tied at the bottom in a knot. The knot was planted in the muddy bottom of the water body with gentle push of the toe. A spacing of 1.5 m x 1.5 m was maintained between planting spots. About 4400 bundles of seedlings (each containing 3-4 seedlings) were generally required to cover an area of one hectare. The vegetative growth continued for three months *i.e*. from mid-June to mid-September and crop covered entire surface of the water body within September. N:P:K fertilizers @ 40:60:40 ha^{-1} were also applied. One third

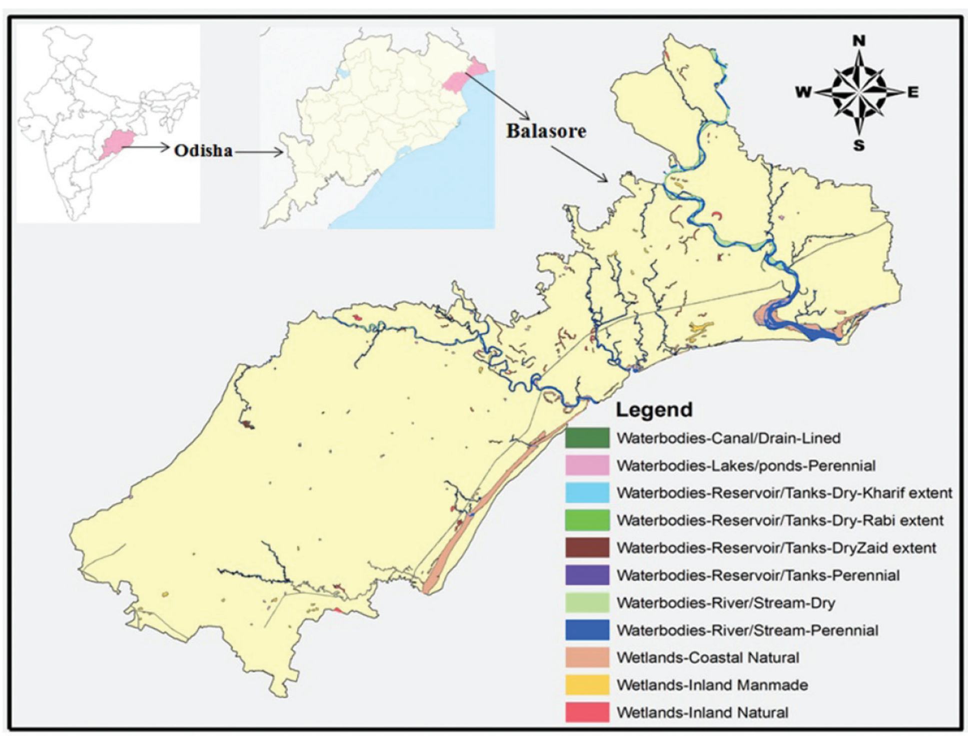

Fig. 1. *Different types of water bodies in Balasore district in Indian state of Odisha*

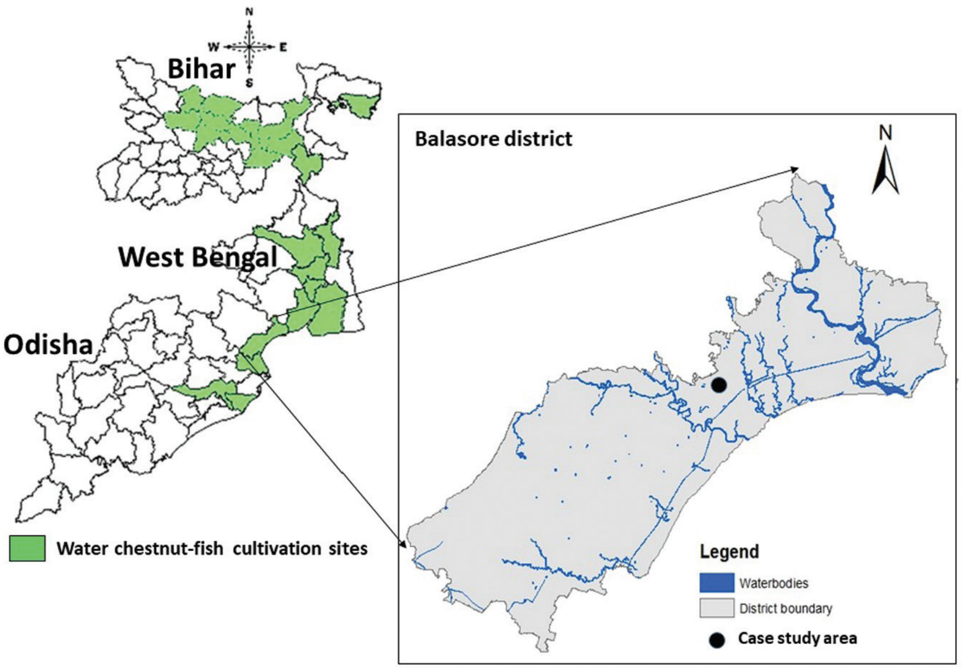

***Fig. 2.** Major delineated water chestnut-fish cultivation sites of Odisha, West Bengal and Bihar states in Eastern India along with case study site*

of N as urea and K_2O as muriate of potash with full P_2O_5 as single super phosphate was applied as basal. The rest 2/3rd N and K_2O was applied in two splits at second and fourth months after planting.

Aquaculture operation

Air breathing fish (*Clarius batrachus*) was released during mid-August 2015 when water chestnut crop established full canopy growth as release of fish at the time of crop planting may dislodge the knot from mud bottom affecting the crop stand. Stocking density of *Clarius batrachus* (15g mean body weight, MBW) was @ 5000 fingerlings ha^{-1} during 2nd week of August (total 17500 fingerlings for 3.4 ha area). Fish feed (soya meal + rice bran + fish meal: 30:55:15) was given @ 3% of MBW, twice a day (7.00 to 8.00 A.M. and 4.00 to 5.00 P.M.). Fish was harvested in the month of February after complete harvest of water chestnut. Monthly fish samplings were carried out for assessment of growth and general health of fish. For this purpose, each time 30 fishes were sampled. The sampled fishes were measured (in cm), weighted (in grams) and released back into the system after sampling. Phyto- and zoo-plankton estimation, weekly observations (samples were collected between 7.30 - 8.30 A.M.) of water quality (temperature, pH, dissolved oxygen, total alkalinity, transparency, primary productivity, total suspended solids, dissolved organic matter, nitrite, nitrate, ammonia, etc.) and monthly observations of soil quality (pH, available N, P and organic carbon) were recorded using standard method (APHA, 1989; Biswas, 1993).

Apparent feed conversion ratio (AFCR) was calculated as dry weight of total feed given in kilograms/ harvested biomass of fish in kilograms. To evaluate production performance, performance index (PI = Per day increment in g x Survival rate in %) was estimated (Mohanty, 2015). Economic indices of water productivity (Mohanty *et al*., 2009) were estimated ({Total economic value of the produce (INR) - Production cost (INR)}/ total water use (TWU) in m^3) where, TWU (probable inflows to ponds) = initial water filling (W_f) + management additions or regulated inflows (I) + precipitation (P) + runoff (R). The statistical analysis for standard error of the treatment means and least significant difference were calculated following Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Characterization of water bodies

The characterization of waterlogged areas showed 17 different types of water bodies and waterlogged areas in Odisha. But mainly three types of water bodies *viz*. inland natural wetlands, coastal natural wetlands and manmade wetlands categories were found suitable for fitting in integrated water chestnut-aquaculture cultivation intervention because of suitable steady water regime. The Balasore district in Odisha showed highest man-made waterlogged area of 569.98 ha (Fig. 1). In the district from a study area of 92452.61 ha, 607.87 ha was found suitable for cultivation of integrated aquaculture with water chestnut due to favorable water regime as shown in Fig. 2. One such representative area in Haldipada block of Balasore district was further selected for performance assessment of integrated water chestnut and aquaculture cultivation as case study among these delineated waterlogged areas.

Aquatic environment and water chestnut crop growth

The pH of water bodies was near neutral (pH 7.0) during monsoon (July to September) and remained nearly unchanged till 2nd week of October before declining at final stages of crop growth during November-December period. The water level of the water body increased with arrival of monsoon. The water level increased steadily till 1st week of October to up to 2.21 m depth before fall to 0.61 m at the end of growing season of water chestnut (Fig. 3). The temperature of water bodies also decreased consistently with increasing age of crop from the month of June onwards and showed a significant drop in the month of November, with arrival of winter season.

The plant height increased steadily and concomitantly with increase in depth of water in the field. As height of plant increases with the increase in water level, water chestnut crop adapts well under increasing level of water in low lying submergence prone areas. Therefore, the leaf crown remained afloat avoiding submergence with increase in level of water. The increasing trend of plant height showed significant correlation (r = 0.82*, significant at 5% level, n = 18) with rising level of water depth. Similar increase in plant height of water chestnut was reported with increase in water level earlier also and was cultivar specific (Roy Chowdhury *et al*., 2003). This property of stem elongation in water chestnut crop has a significant implication for avoiding submergence and survival of the crop in low lying submergence prone areas. The crop resilience with increase in water level makes it suitable for cultivation in submergence prone areas providing insurance against vulnerability to excess water situation. The leaf area per plant increased from July (one month after planting), exhibiting exponential growing during the month of August and September and reached its peak in the month of October. Thereafter, the leaf showed a declining trend till the withering of the crop in December (Fig. 4). Even though scanty number of fruits appeared from last week of August, extensive fruiting of water chestnut crop started from the month of September onwards. The range of productivity in each harvest was as low as 0.02 t ha^{-1} to as high as 0.28 t ha^{-1} in a single day. The cumulative yield from water chestnut crop was 11.09 t ha^{-1}. The fruits are consumed either raw as fresh fruit or mature fruits were dried in open air under sunlight to make flour from dry kernel by harvesting fruits at right stages depending upon its use as fresh fruit or to make flour (Roy Chowdhury et al., 2004, 2009). The yield of water chestnut started dwindling from the month of November onwards and harvest was completed by the end of November.

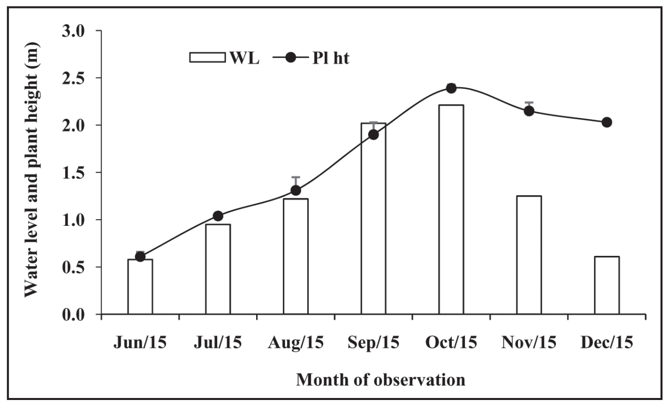

Fig. 3. *Changes in water level and plant height in the experimental field growing water chestnut and aquaculture in delineated waterlogged area. Each value is the mean of three replications ± SE.*

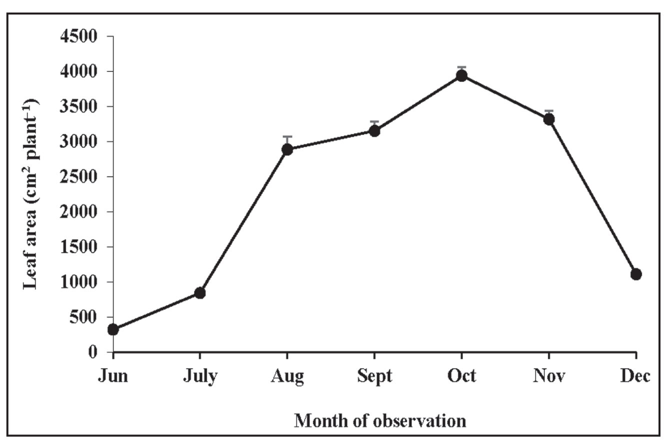

Fig. 4. *Changes in leaf area (cm^2) per plant of water chestnut at different growth stages during experimental period (June – December, 2015)*

Aquaculture

The dissolved oxygen (DO) concentration, pH of water body and total alkalinity showed a decreasing trend with the advancement of rearing period, while increasing trend of nitrite, nitrate, ammonia and organic load were recorded toward the latter part of the experiment. The decreasing trend of DO in the presence of water chestnut and fish was mainly due to the gradual increase in surface coverage and vegetative decomposition, resulting in higher oxygen consumption and increased fish biomass. Further, decomposition of organic matter (feed) that requires additional oxygen and fluctuation in plankton density resulted in higher oxygen consumption (Mohanty, 2010). Gradual increase in nitrite, nitrate and ammonia were attributed to intermittent fertilization, increased level of metabolites and decomposition of plant material and/or unutilized feed in absence of water replenishment. At any given point of time, other water quality parameters and plankton population did not register any specific trend. Phytoplankton population was dominated mainly by diatoms and green algae (62%) whereas, zooplankton population was dominated by copepods and rotifers (38%).

Average primary production in the first month of rearing ranged between 141.3 ± 42.4 mg carbon (C) m^{-3} h^{-1}, which deteriorated further (66.6-97.0 mg C m^{-3} h^{-1}) with the advancement of rearing period. This low primary production was probably due to fixation of nutrient ions by suspended particles as well as rich organic matter. Soils of the experimental fields were clayey. During the experimental period, the composition of sand, silt and clay was 31.8%, 20.2%, and 48.0 %, respectively. Organic carbon (%), available N and P in soil (mg 100 g^{-1}) varied between 0.63-0.75, 13.1-14.7 and 1.28-1.36, respectively at the beginning of the experiment. The gradual increasing trend of organic carbon, available N and P in the soil towards later part of the culture was possibly due to (1) the additional nutrients from the fish feed and feces, (2) fish grazing on the photosynthetic aquatic biomass and other components of the system, thereby aiding in nutrient cycling, minimizing N losses and facilitating P release from the sediment (Mohanty, 2015). The sediment characteristics were indicative of a medium productive soil group (Banerjea, 1967).

The average growth of *C. batrachus* was 149.6 g MBW, while the average performance index (PI) was 49.1. Fish was harvested in the month of February after complete harvest of water chestnut. The additional yield from air breathing fish was 0.47 t ha^{-1}, while the apparent feed conversion ratio (AFCR) was 1.04. In this study, existence impact of water chestnut on production performance of catfish appeared promising. In this system, fish gets sufficient natural food from the system through effective utilization of ecological niches, thus minimizes the supplemental feed requirement in terms of AFCR (1.04). Availability of aquatic insect, periphytic algae and benthic organisms that help, reduce the supplemental feed input. The moderate survival (62.63%) and growth rate of catfish with water chestnut was probably due to cannibalism, competition for space and nutrient, low primary productivity and low intensity of light penetration, that triggers growth.

Economics of catfish-water chestnut farming

The total cost of cultivation of water chestnut cum aquaculture was ₹ 1,43,000 ha^{-1}. Labour component constituted the major share (43%) of cost of cultivation in water chestnut farming (Table 1). The farmers had to engage labour for cleaning the pond, planting, fertilizer and pesticide spraying and harvesting. Pesticide, fertilizer and seedling cost constituted remaining portion of cost of cultivation. The average productivity of the crop was 11 t ha^{-1} and the farmers had very good access to the market. The assured price of harvested water chestnut was ₹ 20 kg^{-1} throughout the season as per the prevailing market rate. The additional return from air breathing fish was approximately 0.47 t ha^{-1} @ ₹ 200 kg^{-1} adding another ₹ 94,000/- to gross return. Hence, the gross returns and net income obtained by the farmers was found to be ₹ 3,14,000/- per ha and ₹ 1,61,000/- per ha respectively. The gross water productivity of aquaculture alone was ₹ 7.9 m^{-3} which was enhanced further to ₹ 16.3 m^{-3} through integrated cultivation of water chestnut with catfish.

Increasing productivity of waterlogged land is a challenge and integrated water chestnut and aquaculture cultivation has potential for adoption in such ecosystem. It was observed from our experiment that the water productivity (₹ 14.3 m^{-3}) as well as net return (₹ 1,17, 000/- ha^{-1}) can be enhanced by practicing integrated water chestnut and aquaculture system when compared to sole aquaculture practice. The delineation of potential areas through remote sensing and GIS (geoinformatics)

Table 1. *Cost of cultivation of water chestnut crop at Haldipada, Balasore district during the year 2015*

Sl.No.	Cost component	Cost per ha (₹)
1.	Seedling cost	10,000
2.	Cleaning of pond	10,000
3.	Lease amount of land	7,000
4.	Fertilizer cost	14,000
5.	Pesticide cost	16,000
6.	Labour for fertilizer, pesticide application, planting and harvesting etc. (280 man-days @ ₹200)	56,000
7.	Imputed value of family labour (60 man-days @ ₹200)	12,000
8.	Miscellaneous cost including aquaculture activity	28,000
9.	Total cost of cultivation	1,53,000
10.	Income from water chestnut	2,20,000
11.	Income from fish	94,000
12.	Net income	1,61,000

could provide solution for identifying suitable areas for such intervention thereby to bring additional areas under cultivation for improved socio-economic livelihood of the farming community in waterlogged areas.

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