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Engineering aspects of aqua farm design for sustainability of environment and aquaculture

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ABSTRACT

Engineering aspects of farm design is an important asset for the development of sustainable aquaculture and environment. The aquaculture map prepared from IRS 1C- LISS III satellite data using Geographic Information System indicated that the area under aquaculture was 328 ha in and around Pichavaram, Cuddalore district, Tamil Nadu. Farm design details like slope of primary and secondary dikes, seepage control measures, pond bottom slope, pond and water spread area were measured from aquaculture farms located at Pichavaram in Tamil Nadu and compared with standard design parameters. Soil characteristics like pH, electrical conductivity, porosity and water holding capacity of the farms ranged from 7.51 to 8.29, 6.18 to 15.75 dS/m, 15.21 to 29.71 % and 20.7 to 36.8 % respectively. The velocity in the drainage channel varied from 0.32 – 0.73 m/sec. The seepage rate was as high as 5.2-13.1 cm/day in soil due to sandy nature. The texture of the soil varied from loamy sand to sandy loam. Village based drainage network is recommended to facilitate proper drainage of wastewater from aquaculture farm.

Introduction

Traditionally aquaculture ponds are earthern ponds, constructed in areas where the soil has sufficient clay content to prevent leakage of water (Singh, 1993). The fast growth rate of the shrimp industry has resulted in the indiscriminate development of shrimp farms without prior site selection and environmental survey. The setbacks witnessed in coastal aquaculture due to disease outbreaks all along the Indian coast are mainly due to the unplanned and mushroom growth of aquaculture farms. Proper designing of aqua farms is very important for better management and thereby to overcome and/or minimize the adverse impacts on environment and aquaculture. But, most of the existing farms are not constructed as per technical designs or standards and there are many deficiencies in designs, construction and management of farms (Omprakash, 1994). As a consequence, majority of the farms constructed are not stable to withstand the hazards encountered in coastal region (Mukherjee and Ghosh, 1987)

The basic requirements of coastal aquaculture farm are ponds, water distribution structures and good soil and water quality parameters. Site selection and adequate knowledge in coastal aquaculture engineering are one of the most important factors governing the success of aquaculture. To build a good farm, it is essential to have enough water of desirable quality and a land of satisfactory topographical characteristics with impervious soil of suitable type. Engineering and construction costs of pond aquaculture constitutes between 50-60 % of the total capital costs of the venture. The earthwork in the construction of the ponds, canals, levees alone comprises 35-50% of the construction costs (Chamberlain *et al.*, 1985). If capital costs can be minimized while still maximizing productivity and reducing the risks, the farming operation will be more profitable. A proper layout of the farm significantly reduces the cost of construction and ensures the smooth and trouble free operation of the various facilities and structures allowing proper management of production activities (Upadhyay, 1994).

The high rate of expansion of pond aquaculture is largely due to the results of scientific research and industrial experiences. However, engineering aspects of farm design is relatively neglected (Griffin *et al.*, 1993) and in most cases ponds are constructed with the past experience gained in the field. Water loss due to seepage from aquaculture ponds has been major problem in coastal areas as it leads to salinisation of adjacent agricultural areas and drinking water resources. Seepage from aquaculture ponds results in poor productivity due to nutrient loss and fluctuation in the water quality parameters. Ponds constructed with good design and materials prevent saline water from seeping out and contaminating freshwater reserve and adjacent agricultural lands (Storehoff and Hovers, 1996).

The problems recently faced by this sector have put pressure on research and development organizations to come up with eco - friendly farm design. The present study was carried out with an aim to collect the existing design patterns and soil characteristics of the aqua farms and to analyse and finalise the suitable engineering aspects needed for their sustainability.

Materials and methods

The shrimp farms at Pichavaram area in Cuddalore District of Tamil Nadu were selected for the present study. Pichavaram lies in between 79045' - 79052' E and 11022' - 11030'N and the mangrove ecosystem in Pichavaram is well known for its luxuriant growth of mangrove plants with high productivity and diversity of fauna and is abound with rich detritus, nutrient salts, vitamins, trace elements etc. Pichavaram mangroves receive freshwater during the late pre monsoon to early post monsoon period through two major canals. A main channel from Coleroon River contributes considerable amount of freshwater before its entry into the Bay of Bengal. Khan Sahib Canal, which is mainly used for irrigation, supplies freshwater to some extent. Brackishwater enters the mangrove area through the Vellar and Coleroon estuaries.

The aquaculture map was prepared using LISS III data of IRS -1C satellite received from National Remote Sensing Agency in ERDAS IMAGINE platform. Farm design details like area, pond bottom slope, width and slope of main and secondary dikes, drainage pattern, material of construction, pond lining, distance from the agriculture field and yield were collected. The Latitude and Longitude of the farms were measured with Global Positioning System (GPS).

The soil samples collected from the farms were air-dried, powdered and sieved through a 80 mesh sieve. Soil pH was measured as soil water pH by potentiometric method using 1:2.5 soil - water suspension. The same soil-water suspension prepared for pH estimation was used for EC determination by conductivity meter (Piper, 1966). The porosity was calculated from bulk and particle densities (Danielson and Sutherland, 1986). Water holding capacity was determined by Keen's box method and Soil texture was analyzed by pipette method (Piper, 1966). The seepage rate was measured by still water pool level method. The depth of water in each pond was checked with a J hook gauge having an accuracy of + 1 mm, daily in the morning and the evaporation rate was measured using the evaporation pan. Pan evaporation was then converted to pond evaporation with the coefficient of 0.83 (Boyd, 1985). The seepage rate was calculated from the difference between the total water loss and pond evaporation value.

Results and discussion

Aquaculture map of Pichavaram (Fig.1) indicated the development of aquaculture in the region was 328 ha in 2003. The commercial aquaculture ponds were developed in late 1980's and increased to 328 ha by 2003. The details of farm design are given in Table 1. The pond area ranged from 0.8 ha to 1.2 ha with square or rectangular shape. Rectangular ponds facilitate a better water circulation and avoid dead zones (Omprakash, 1994). The maximum designed water depth was one metre. The water spread area ranged from 60 to 70% of the total farm area. The pond bottom was provided with a slope of 1000:1 to 1000:3 towards the drain to facilitate proper drainage whereas the recommended slope was 1000:1 to 1000:5.

TABLE 1: *Design details of shrimp farms*

Location	Farm area (ha)	Average pond area (ha)	Mean water spread area (ha)	Number of ponds	Velocity of water in drainage canal (m/sec)
11° 25' 32"N 79° 46' 21" E	4	0.8	2.8	5	0.32
11° 25' 4""N 79° 46' 36" E	12	1.0	9.6	12	0.46
11° 25' 36"N 79° 46' 23" E	2	1.0	1.5	2	0.40
11° 25' 30"N 79° 46' 20" E	9	0.8	7.2	11	0.37
11° 25' 51"N 79° 46'44"E	9.4	0.9	7.52	10	0.52
11° 25' 42"N 79° 46' 57" E	2	1.0	1.56	2	0.59
11° 25' 46"N 79° 46' 59" E	5	1.0	3.5	5	0.61
11° 29' 12"N 79° 46' 34" E	4	0.9	3.2	4	0.67
11° 25' 49"N 79° 47' 06" E	1.5	0.7	1.05	2	0.72
11° 25' 49"N 79° 47' 06" E	12	1.0	8.4	11	0.73

Fig 1. Aquaculture area in 2003 delineated from IRC 1C, LISS III data

(Upadhyay, 1994).

The top width of 1.5 - 2 m peripheral dikes indicated that it needs to be increased to 2.4 m. The slope of the peripheral dike ranged from 1.5:1 to 2:1 whereas 2:1 is recommended as per design norms (Table 2). The periphery of bunds were located very close to the creek in most of the farms. However, it should be located 30 m away from the riverbanks for ecological consideration as well as protection against floods and wave action. There is a need to relook at the layout of farms in addition to improving the structural stability of the farm components and water management by water control structures. The dikes were not lined and the free board was maintained between 0.4 and 0.5 m in main dikes. A minimum free board of 0.6 m is necessary to prevent overtopping of dike. The dikes should be lined with clay to avoid erosion and seepage problems.

The width of secondary dike was 0.8 to 1.0 m where as the recommended width is 1 to 2 m (Upadhyay, 1994). The orientation of longer axis of the pond with wind direction will be helpful to increase the water movement by wind action. This increases the dissolved oxygen content in the water and reduces the fluctuations of water temperature. Clay soil is best suited for constructing bunds since it has good water retention properties. Such bunds cannot be easily eroded by wave or tide actions and will prevent seepage problems.

TABLE 2 : *Details of pond bottom, main and partition dikes*

Particulars	Range in shrimp ponds	Standard parameters
Main Dike		
Top width (m)	1.5 – 2.0	2.4
Slope	1.5:1 – 2.:1	2:1
Free board (cm)	40-49	60
Partition Dike		
Top width (m)	0.8-1.0	12.1:1
Slope	1.8:1 – 2.5:1	2.5:1
Free board (cm)	20-27	30
Pond bottom slope	1000:1 to 1000:3	1000:1 to 1000:5

The stability of a homogeneous earth fill dike and effectiveness of its side slope can be rectified by using Taylor's stability number (Singh and Punmia, 1970) which suggests a minimum factor of safety of 2 against slip failure. To control the seepage loss and impart perfect stability of the dike, the crest of dike should be sufficiently wide and slopes flatter so that the parabolic curve of the seepage line falls with in the body of the dike. Another major problem in farm maintenance is tunnelling caused by eels, crabs etc in the dikes and ponds which can be counteracted with success by the application of quick lime in the burrows (Mline, 1972).

The velocity of water in the drainage channel ranged from 0.32 - 0.73 m/sec. In most of the farms, the drainage channel slope is found to be below 0.05% which will result in silting. Lining of channel with grass will to a large extent, prevent silting and it is usually done above the water line, leaving the main channel section conveying the water free from grass or other vegetation in to farms.

The average soil pH and EC values of the shrimp ponds ranged from 7.51 to 8.29 and 6.18 dS/m to 15.75 dS/m, respectively (Fig.2). The soil salinity was high in some places due to the effect of sea water back flow during high tides. As per the soil survey report of Govt. of Tamil Nadu, the soils of the shrimp culture areas were saline even before the start of aquaculture (Anon, 1978). The water holding capacity was less (20.7 to 36.8%) in most of the farms because of high sand content as this is directly related to the porosity and clay content of the soil. The porosity of the soils ranged from 15.21 to 29.71 % and it is found to be proportional to the sand content in the soil.

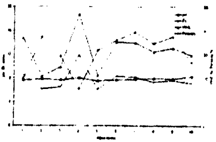

Fig 2. Soil characteristics in shrimp culture far ...

The seepage rate ranged from 10.2 - 13.1 cm/day (Fig.2) in the ponds because of the sandy nature of the soil. Seepage of saline water from aquaculture ponds was an environmental problem since it results in salinisation of soil in nearby agricultural land and drinking water resources. High seepage rates not only result in water loss but also reduce the pond fertility and thereby adversely affect the crop. Pond constructed in fine-grained soil is confronted with the problem of water retention, as losses due to percolation in such soils are quite considerable. The extent of water loss through the pond bottoms and dikes affect both the design and management of ponds. Pond bed and sides can be covered with hard clay deposited in layers and well compacted. Chemical sealants like sodium polyphosphate may be mixed with soil to make it denser and impermeable.

The texture of the soil varied from loamy sand to sandy loam (Fig.3). There was not much difference among the textural separates viz., sand, silt and clay in shrimp farm ponds. Since finer particles are more active than the coarse ones, the magnitude of activity of the soil phase is determined largely by its textured composition. Analysis of soil texture and other physical and chemical properties of interest in pond construction are used to determine if site soils are suitable for

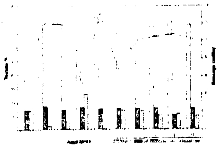

Fig 3. Soil texture and seepage rate in shrimp culture farms

building ponds (Hajek and Boyd, 1994). Boyd (1976) showed that textural and chemical properties of soils have direct bearing on the productivity of the ponds.

Risk of disease outbreaks and poor water quality often result when efforts to increase production are unsupported by improved management strategies which include the farm design and construction. Many of the problems affecting both shrimp culture and the environment could be avoided by improved site selection and proper design. Small farms were started without any prior environmental or site surveys. There was no buffer zone between aqua farm and agricultural farm which resulted in salinization of land in certain areas and subsequently led to various environmental problems.

In most of the farms, inlets were constructed nearer to the outlets of the adjacent farms causing deterioration with quality of source water which led to the outburst of deadly viral diseases. Settlement ponds are therefore needed to remove the total suspended solids because most of the farm drainage canals are directly connected to the creek. Drainage water from one pond carries metabolic load and letting the same water into another culture system will have adverse impact on the growth of the animals and quality of water. Drainage network is necessary to facilitate proper drainage of wastewater from the farm and to ensure that used culture water does not find its way back into any other farm. Since, the individual farmer is not able to provide the wastewater treatment system, through drainage network, the waste water can be taken to a common treatment system which can be installed in a capacity basis.

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