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Tsunami and Coastal Aquaculture: Implications for Soil Profile, Structure and Productivity

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Tsunami

It was a tragic moment when several parts of Sumatra, Indonesia, Andaman and Nicobar Islands, Sri Lanka and India were devastated by deadly tsunami tidal waves with speed of about 500 km hr^{-1} on Sunday 26th December 2004. The tsunamis caused extensive damage in southern regions of India and Andaman and Nicobar Islands affecting a total of 2,260 km of coastline. The waves were reported to be as high as 3-10 metres in southern India and penetrated from 300 m to 3 km inland. The fisheries sector in Tamil Nadu, Andhra Pradesh and Andaman and Nicobar Islands has suffered major damages in terms of lives, boats, gear and to the infrastructure such as harbours and fish landing centres. Many hatchery facilities in Kovalam, Marakanam and Pondicherry belt were severely affected by damages to pump houses, fencing etc (Anonymous 2004). Aqua farms to an extent of 5753 ha were damaged in Tamil Nadu. Shrimp farms in Cuddalore, Chidambaram, Sirkali, Tharangampadi, Vedaranyam, Nagapattinam and Velankanni were severely affected with collapsed bunds and damage to the equipment including motors and pumps (CIBA 2005).

Shrimp farms in the Vellar estuaries (Chidambaram, Sirkali) were heavily damaged from seawater inundation. About 11,000 ha of agricultural land damage was reported in the Andaman and Nicobar Islands due to submergence of about 1-3 m land after tsunami/earthquake. In addition, soil salinity has increased in the low-lying coastal areas and has caused extensive damage to some of the best available cultivable land in the islands and main land. Post-tsunami, the salt-ingressed areas have increased and prime agricultural lands have become saline. Indian Council of Agricultural Research (ICAR) recommended diversification of farming by replacing rice-paddies with integrated aquaculture-based farming (*ibid*). In this context it is necessary to understand the nature of coastal soil and the changes in the soil after introduction of brackishwater aquaculture.

Brackishwater Aquaculture

Coastal aquaculture has been recognised as a thrust area among the fisheries development programmes of the country. Shrimp farming, a biological production activity, has been identified as one of the key areas for enhancing shrimp production and has been gaining importance in India for the past few years. India has vast potential for brackishwater aquaculture. In physical terms, the country has a long coastline of 8,129 km, including the mainland, Andaman and Nicobar Islands and Lakshadweep. Fourteen large river systems and innumerable small seasonal coastal rivers drain into the seas. These form extensive estuaries, backwaters, lagoons, coastal lakes, tidal creeks and mangrove swamps. The adjoining land, due to salt incursion, becomes unsuitable for agricultural crops but would be suitable for brackishwater aquaculture. Although estimates of available brackishwater area have varied, 1.19 million ha (Mha) is considered to be amenable for brackishwater aquaculture. However, the effective area utilisable for brackishwater aquaculture will be further restricted by oceanographic factors such as cyclones, storms, storm surge and storm waves; rainfall fluctuations; topographical and engineering constraints; soil and water quality; demand by other sectors such as agriculture, tourism, ports, salt industry, forest resources, and mangrove conservation zones; infrastructure availability; defence considerations and

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pollution problems. The coastal area of the country has 2.54 Mha of salt-affected soils which are unfit or marginally fit for agriculture, excluding 0.57 Mha under mangroves. Shrimp farms have been constructed on variety of coastal lands – intertidal fallow land, dry and saline fallow land, unproductive and marginal agricultural land, and to a lesser extent in wetlands like marshes and mangroves.

Besides the coastal agro-ecological zones (Eastern and Western Coastal Plains and the Andaman and Nicobar and Lakshadweep Island Zones), there are large tracts of salt-affected land in the hot, semi-arid eco-region of northern plain and Central Highlands in the states of Haryana, Rajasthan and Uttar Pradesh, with surface and sub-soil brackishwater. These resources are also to be considered for their aquaculture potential. India has a rich resource of underground saline water that is not commonly used for agriculture and could be used to raise marine shrimp. Inland production of marine shrimp provides an alternative to traditional coastal aquaculture where land costs and user conflicts can inhibit commercial development.

Shrimp aquaculture requires natural resources like land, water, and biological resources like seed and feed. The quality and quantity of available resources and their management, therefore, play a key role in the economic success and long-term sustainability of coastal aquaculture. Shrimp culture technology and the system of culture to be undertaken depend entirely on the site characteristics. Regarding site selection other than hydro-meteorological parameters (tidal amplitude of water source in the area, rainfall, wind direction and velocity, flood levels and frequency, time of occurrence of natural calamities; cyclones and storms), social, legal and economic conditions, the soil and water quality of the area should be taken into consideration. The natural resources *viz.*, land and water, if poorly planned and managed, can result in irreversible environmental damage and may lead to ultimate loss in economic gains.

Coastal Soils – Characteristics and their Suitability to Brackishwater Shrimp Farming

The nature of pond bottom soil is considered to be of great importance in brackishwater aquaculture. Less attention has been paid to the management of pond bottom soil quality. There is increasing evidence that the condition of pond bottoms and the exchange of substances between soil and water strongly influence water quality (Boyd 1995). Productivity of brackishwater aquaculture system depends on the nature and properties of bottom soils (Hickling 1962). The main source of nutrient elements is the reserve in the bottom soil, which through the activity of several groups of microorganisms is transferred into the soluble forms (Mandal 1962). Interactions between soil and water that influence water quality in ponds must not be ignored because poor soil condition can impair survival and growth of aquaculture species. For example, ponds with acidic soils, which are characterized by low pH and total alkalinity, unless applied, may be unsuitable for aquaculture. Boyd and Munsiri (1997) predicted the availability of nutrients in aquaculture ponds from bottom soil properties.

Properties of soils should be considered in selecting a site, designing earthwork, and specifying construction methods for a water-tight pond with stable levels and bottom slopes. Some soils may have undesirable properties like potential acid sulphate acidity, high organic matter content or excessive porosity which comes under moderate rating according to the classification of Hajek and Boyd (1994) *i.e.* these soils have one or more properties that will require special attention for the designated use. This degree of limitation can be overcome or modified by special planning and management such as liming, organic manuring and additional compaction of soils. The soils may be considered suitable for brackishwater aquaculture upon managing these moderate limitation properties.

The Central Institute of Brackishwater Aquaculture (CIBA) has conducted studies on the physico-chemical properties of east coast and west coast soils of India for their suitability to brackishwater aquaculture. Texture of the soil has direct bearing on the productivity of the ponds. The importance of soil texture on the production of the brackishwater fish ponds has been emphasised by Djajadiredja and Poernomo (1972). In brackishwater shrimp ponds, benthic productivity is more important than the production of plankton. A clayey soil rich in organic matter encourages the growth of benthic blue algae, which along with the associated microorganisms forms the main food for most of the brackishwater animals. Aquaculture ponds usually are located in mineral soils that contain less than 5% organic carbon. A few aquaculture ponds are built in organic soils, but such soils are not well suited for aquaculture. In mineral soils, texture is important because light texture (sandy or loamy) facilitates the exchange of dissolved oxygen and other substances between water and sediment. Also, when ponds are drained and dried between crops, light-textured soils dry quicker and aerate better than the heavier-textured soils. Most of the texture classes given for terrestrial soils using a soil triangle are suitable for pond aquaculture.

Clayey soils are best suited for constructing bunds and have good water retention properties. Such bunds cannot be easily eroded by wave or tidal action. Sandy soil is porous and very poor material for constructing bunds. Therefore, brackishwater soils with moderately heavy texture are ideal for aquaculture. Sandy clay, sandy clay-loam and clay-loam are some of the textures suitable for aquaculture. Joseph *et al.* (2000) reported that soil texture in the brackishwater shrimp pond soils at Nellore (Andhra Pradesh), was clay-loam (sand : 40.9-41.5 %, silt : 12.3-13.7%, clay : 44.8-46.8 %) whereas, at Tuticorin, Tamil Nadu soil was sandy clay loam (sand: 64.3-66.1 %, silt : 13.5-17.2 %, clay : 16.8-20.4 %). The presence of higher amounts of sand fractions in surface horizons of many soils may be due to impoverishment of finer particles by surface runoff water. The difference of sand/silt ratio was always more than 0.2 between the adjacent depths, confirming the lithological discontinuity, instead of homogeneity of parent material.

Some of the soil characteristics of east coast and west coast are presented in table 1 (Joseph *et al.* 1997). The silt load in west coast was very high (55.5%) as compared to East coast (12.87%), which may have impact on the water quality. Other parameters can be manipulated by suitable management practices. The soils of brackishwater fish ponds of West Bengal have favourable physico-chemical properties for productivity, contain comparatively higher amounts of available phosphorus but lesser amounts of available nitrogen and organic carbon than those of nearby freshwater ponds (Chattopadhyay and Mandal 1986). Higher electrical conductivity in these soils is due to inundation of saline water (Maji and Bandyopadhyay 1996). Chattopadhyay and Mandal (1980) reported that high alkaline earth carbonates in coastal soils would be useful in counteracting some of the possible harmful effects of organic manuring.

Concentration of the heavy metals in most places is within the safe limits. The concentration of heavy metals in pond and Kandaleru creek sediment samples (average values of source and discharge points) indicated the presence of zinc, lead, copper, chromium and nickel, whereas cadmium and mercury were below the limits of analytical detection (Muralidhar *et al.* 2003) (Table 2). There is no apparent anthropogenic input of heavy metals in these areas, as there are no nearby human settlements or industries. The average values of these metals in pond and creek sediments did not show much difference. Among heavy metals, zinc content was high compared to other metals in pond (158 mg kg^{-1}) and creek (162 mg kg^{-1}) sediments. Although impact of the heavy metals may not be serious at present but in future, their concentrations may increase due to continuous entry of effluents from industries and may bring about changes in biological spectrum. Hence, the continuous monitoring of the environment is essential.

Table 1. Soil characteristics of coastal areas of India

Parameter	East Coast	West Coast
Sand (%)	40.0	18.4
Silt (%)	12.9	55.5
Clay (%)	47.1	26.1
EC (dS m^{-1})	11.7	9.6
pH	8.2	8.8
Organic carbon (%)	0.92	0.20
$CaCO_3$ (%)	2.2	16.5
Available N (mg 100 g^{-1} soil)	30.2	11.1
Available P (mg 100 g^{-1} soil))	4.25	2.41

Source: Joseph *et al.* (1997)

Table 2. Average values of heavy metals (mg kg^{-1}, dry weight) along with standard deviation in Kandaleru creek and shrimp ponds sediment at Pudiparthi, Nellore, Andhra Pradesh

Heavy Metals	Pond Sediment	Kandaleru Creek Sediment*
Zinc	158.0 ± 7.8	162.0 ± 8.5
Lead	12.6 ± 1.8	16.9 ± 2.1
Copper	38.2 ± 4.8	32.0 ± 3.9
Chromium	14.1 ± 1.8	12.9 ± 1.1
Nickel	42.0 ± 3.9	46.2 ± 3.1
Cadmium	BDL	BDL
Mercury	BDL	BDL

*Average value of source and discharge points in the creek
BDL - Below detection level
Source : Muralidhar *et al.* (2003)

Changes in Coastal Soils following Introduction of Brackishwater Aquaculture

A satisfactory pond soil is the one in which mineralization of organic matter takes place rapidly and nutrients are adsorbed, held and released slowly over a long period. Further, in bottom soil, a series of chemical and biochemical reactions take place resulting in either the release of nutrients from soil to water or absorption of nutrients from water by the soil and microbial population. This process governs the growth and population of the micro- and macro food organisms in the fish/shrimp ponds. The soil properties suitable for shrimp farming are given in table 3.

The word soil is used for the weathered surface layer of the earth's crust in which plants grow, various animals burrow, and humans have frequent contact. Sediment is used to refer to geological material that has been suspended and transported by water to another place where it settles in the water and forms a deposit. In many places, the soil was formed by sedimentation. In describing various physical, chemical, and biological processes occurring in the pond bottom, it is convenient to refer the bottom deposit as sediment. Usually the sediment layers in the bottom of an aquaculture pond will be considered as pond soil. Normally, the newly finished pond bottom is subsoil low in organic matter and nutrient content. After filling with water, various processes begin to transform the bottom of a new pond into a pond soil.

The recent taxonomic classification of pond soils not only uses data on soil physical and chemical properties, but it also relies heavily on the appearance of the soil profile. It includes primary soil properties *viz.* texture, sediment thickness, organic matter content, and pH and the secondary properties *viz.*, carbon:nitrogen (C/N) ratio, amount of sulphur, amount of carbonate, and sodium content. The condition of the flocculent layer and the surface of the sediment also can be included in the classification system as tertiary properties if desired.

Electrochemical Properties of Soil

When an agricultural land is submerged, the gaseous exchange between the soil and air is drastically curtailed. Oxygen and other atmospheric gases can enter the soil only by molecular diffusion in the interstitial water. The process is 10,000 times slower than diffusion of gas in the gas-filled pores. The diffusion is further slowed down as the path length of diffusion *i.e.* depth of standing water increases. Thus, under aquaculture, soils are more reduced than that under normal paddy cultivation.

Submergence brings about a variety of electrochemical changes in soil. These include (1) a decrease in redox potential of soil, (2) an increase in pH of acid soil and decrease in pH of alkaline soils, (3) changes in the specific conductance of soil, (4) shift in the mineral equilibria of soil, (5) changes in the cation and anion exchange reactions, and (6) sorption and desorption of ions. Submergence with brackishwater adds new dimensions due to the fact that (a) it contains excess of cations and anions, (b) it has high specific conductance, and (c) it contains high amount of sulphate salts unlike the fresh water flooded soils having negligible amount of sulphate salts.

During the shrimp culture period at Nellore, redox potential decreased from -40 to -154 mV, whereas electrical conductivity and organic carbon in soil increased from 17.1 to 29 dS m^{-1} and 0.34 to 0.8%, respectively. Soil pH was slightly acidic to around neutral (pH 6.2-6.9), whereas, in Tuticorin, during the culture period, variation in pH, redox potential, electrical conductivity and organic carbon in soil was not significant and they ranged from 6.8-7.2, -42 to –80 mV, 14 to 19.9 dS m^{-1} and 0.17 to 0.36 %, respectively (Joseph *et al.* 2003)

Microbial Reduction of Soil

The oxidized layer at the sediment surface is highly beneficial and should be maintained throughout the aquaculture crop. Metabolic products of aerobic

Table 3. Soil characteristics for brackishwater aquaculture

Property	Limitation ratings		
	Slight / Suitable	Moderate	Severe / Unsuitable
pH	6.5-9.0	4.5-6.5	<4.5 >9.0
Clay content (%)	>35	18-35	<18
Organic carbon (%)	1.5-2.5	0.5-2.0	<0.5 >2.5
$CaCO_3$ (%)	>5.0	NA	NA
Available nitrogen (mg 100 g^{-1} soil)	50-75	25-75	<25 >75
Available phosphorus (mg 100 g^{-1} soil)	4-6	3-6	<3 >6
Electrical conductivity (dS m^{-1} at 25 °C)	>4	NA	NA
Small stones (>2 mm) (%)	<50	50-75	>75
Large stones (> 7 cm) (%)	<25	25-50	>50

decomposition are carbon dioxide, water, ammonia, and other nutrients. The immediate effect of submerging an aerobic soil is that the aerobic organisms in soil use up the soil oxygen within a few hours and become quiescent or die. As a result the redox potential of soil decreases and the soil constituents undergo reduction. Dissolved oxygen cannot enter rapidly in bottom soil because it must diffuse through the tiny, water-filled pore spaces among soil particles. At a depth of only a few millimeters below the soil surface, the demand for dissolved oxygen by microorganisms far exceeds the rate of dissolved oxygen that can move to that particular depth and as a result, anaerobic conditions develop. The oxidized (aerobic) layer of surface sediment has a lighter colour than the deeper, reduced (anaerobic) sediment. The anaerobic sediment is usually gray or black, and this colour results from the presence of iron containing compound magnetite. In anaerobic sediment, some microorganisms decompose organic matter by fermentation reactions that produce alcohols, ketones, aldehydes, and other organic compounds as metabolites. Other anaerobic microorganisms are able to use oxygen from nitrate (NO_3^-), nitrite (NO_2^-), iron and manganese oxides, sulphate, and carbon dioxide to decompose organic matter, but they release nitrogen gas, ammonia, ferrous-iron (Fe^{2+}), manganous-manganese (Mn^{2+}), hydrogen sulphide (H_2S), and methane (CH_4) as metabolites (Blackburn 1987). Some of these metabolites, especially hydrogen sulphide (H_2S), nitrite, and certain organic compounds, when enter into the water column can be potentially toxic to fish or shrimp. The oxidized layer at the sediment surface prevents diffusion of most toxic metabolites into pond water because they are oxidized to non-toxic forms by chemical and biological activity while passing through the aerobic surface layer. Nitrite (NO_2^-) will be oxidized to NO_3^-, Fe^{2+} converted to Fe^{3+}, and H_2S will be transformed to sulphate (SO_4^{2-}). Thus, it is extremely important to maintain the oxidized layer at the sediment surface in aquaculture ponds. Methane and nitrogen gas pass through the layer and diffuse from the pond water to the atmosphere. These two gases do not cause toxicity to aquatic organisms under normal circumstances. Loss of the oxidized layer can result when soils accumulate large amounts of organic matter and dissolved oxygen is used up within the flocculent layer before it can penetrate the soil surface. Even in ponds without high concentrations of organic matter in sediment, high rates of organic matter deposition resulting from large nutrient inputs and heavy plankton blooms can lead to oxygen depletion in the flocculent layer.

Changes in Available Nutrients of Soil

Transformation of nutrients in pond soil depends considerably on the widely fluctuating salinities of water in ponds during different seasons of the year (Johnson and Guenzi 1963). Muralidhar *et al.* (1999) reported maximum available nitrogen at 20 ppt and the higher salinities having some adverse effect on the microbial population responsible for the process of mineralisation (Mandal 1962; Paliwal 1972; Chattopadhyay and Mandal 1980).

The waterlogging of soil with brackishwater may influence the nitrogen transformations and losses from soil. Under submerged condition organic matter decomposition leads to the formation of NH_4^+-N rather than NO_3^--N. However, there are enough evidences that the loss of N gaseous forms is greatly increased by the increase in soil salinity which is quite high in brackishwater aquaculture. The solubility of Fe and Mn increases under waterlogged condition of soil, and with continued waterlogging considerable amounts of Fe, Mn and other nutrients may get lost from the surface soil due to leaching. This may render the soil deficient in many nutrients, particularly, the micronutrients. The excess solubility of Fe in soil under reduced condition and high concentration of Ca in brackishwater may render the soil as the one with high P-fixing capacity.

Pond soil strongly adsorbs phosphorus, and the capacity of it to adsorb phosphorus increases as a function of increasing clay content (Boyd and Munsiri 1996). Masuda and Boyd (1994) showed that about two-third of phosphorus applied to ponds in feed accumulated in bottom soils and most of the soil phosphorus was tightly bound, with only small amount remaining in water soluble form. Studies on phosphorus adsorption and release by soil conducted under the PD/ACRSP also revealed that pond soils are not a major source of phosphorus to water because soil-adsorbed phosphorus is highly insoluble (Boyd and Munsiri 1996; Boyd *et al.* 1999). Phosphorus released by decomposition of organic matter in pond bottoms is rapidly adsorbed by soil and little of it enters the water.

Nutrient budgets reveal that most of the phosphorus not contained in aquatic animals at harvest is adsorbed by bottom soil or contained in organic matter that settles at the bottom. Nitrogen not removed in the harvest of animals is lost primarily through denitrification, ammonia volatilization, or outflow. A significant portion of the nitrogen may also accumulate in the bottom soil.

Changes in the Ionic Equilibria of Soil

Waterlogging of soil with brackishwater may cause changes in the cation exchange behaviour. Many exchangeable nutrient cations and anions on soil colloids may get lost due to leaching. The exchangeable cationic equilibria may be shifted towards more dominance of Na and Mg which are dominant cations in brackishwater. Under such conditions the soil may develop sodicity on drying, provided there is no accumulated sulphidic material in soil. Exchangeable and non-exchangeable phosphate and other nutrient anions in soil may also be replaced by SO_4^{2-} and Cl^- ions which are dominant in brackishwater and may be lost from the soil making it highly deficient in P and other anionic nutrients.

Accumulation of Metal Sulphides

One of the most striking differences between fresh water submerged soils and brackishwater submerged soils is probably the SO_4^{2-} reduction. Since sulphate salts constitute a major part of salts in brackishwater, reduction of soil under brackishwater results in microbial reduction of SO_4^{2-} to S^{2-} which subsequently precipitates as $FeS.nH_20$ (hydrotroillite) and other insoluble metallic sulphides and accumulates in soil. This imparts black colouration to the submerged soils rich in SO_4^{2-} salts. Reduction of sulphate salts produces considerable amount of H_2S gas which is highly toxic to aquatic animals.

Organic Matter Decomposition

Wave action, rainfall, and water currents from mechanical aeration erode embankments and shallow edges to suspend soil particles. In addition, nutrients added to ponds in the form of fertilizers, manures, and feeds cause phytoplankton blooms that increase the concentration of suspended organic particles. Boyd (1976, 1977) reported that continuous input, deposition, resuspension, and redeposition of particles in a pond resulted in large sand particles settling first in shallower water, followed by silt-sized particles, and finally fine clay particles and organic matter settling in the deeper water. Deeper areas gradually fill in, thus reducing the volume of the pond. Sediment thickness in deep areas of aquaculture ponds usually increases at the rate of 0.5 to 1 cm yr^{-1} (Munsiri *et al.* 1995).

Organic matter settled at the bottom is decomposed by microorganisms. Easily decomposable organic matter, such as simple carbohydrates, protein, and other cellular constituents, is quickly degraded. More resistant material, such as complex carbohydrates and other cell wall components, accumulates due to slow degradation. There is a continuous input of organic matter to the bottom, so microorganisms are continually decomposing both the fresh, easily degradable (labile) organic matter and older, resistant (refractory) organic matter. Organic matter concentration usually is greatest near the sediment surface (Munsiri *et al.* 1995). The ratio of labile organic matter to refractory organic matter also is highest near the sediment surface (Sonnenholzner and Boyd 2000). Organic matter concentrations in pond soils do not continue to increase indefinitely. If aquaculture practices - *e.g.*, species; stocking, fertilization, and feeding rates; water exchange; amount of mechanical aeration; and treatment of fallow bottom between crops remain about the same, the annual input of organic matter and rate of organic matter decomposition also will remain about the same (Avnimelech *et al.* 1984; Boyd 1995). New ponds usually have little organic matter in bottom soil, and the labile organic matter added each year will largely decompose, while a considerable proportion of refractory organic matter will accumulate (Boyd 1995). Over a fairly short period, often after four or five crops, organic matter in the soil will reach a high enough concentration that the annual rate of decomposition of organic matter will equal the annual input of organic matter. At this time, equilibrium will occur and soil organic matter concentrations will remain about the same across the years.

According to Boyd (1995), shrimp pond soil consists primarily of mineral soil (95-98%) and contains only a little organic carbon (2-5%). However, in Nellore District of Andhra Pradesh and V.O.C district of Tamil Nadu, it was observed that the organic carbon content of the soil never increased beyond 1.5 % during culture/harvest (Ravichandran 2000) (Table 4).

Management of Pond Soil

Low pH, high acidity, elevated organic matter concentration in surface sediment and accumulation of soft sediment appear to be the most common problems with pond soils. Hence, soil management in ponds should focus on liming to reduce acidity and increase pH and drying of bottom between the crops. These two procedures can enhance the degradation of organic matter and improve soil quality. Also, soft sediment should periodically be removed from the deeper areas of ponds. Ponds should be managed to prevent large accumulation of fresh organic matter in the flocculent layer or in the upper few millimeters of soil.

Table 4. Organic carbon content in soil from of shrimp culture farms in Andhra Pradesh and Tamil Nadu

Sl. No.	Location of the farm	Organic carbon (%)	
		Culture phase	After harvest
		Nellore District, Andhra Pradesh	
1.	Pudiparthi (4 farms)	0.31-0.72	0.49-1.20
2.	Krishnapatnam (2)	0.40-0.79	0.64-0.92
3.	Tippaguntapalem (1)	0.45	0.85
4.	Ankalapaturu (1)	0.64	0.81
5.	Balajipalem (1)	0.36	0.35
6.	Ananthapuram (1)	0.34	60.82
7.	Kothakoduru (1)	0.42	0.53
8.	Thupilipalem (1)	0.39	0.94
		V.O.C District, Tamil Nadu	
9.	Taruvaikulam (1)	0.12-0.22	0.32-0.38

Conclusion

The tsunami flood can be expected to initiate a series of damage events, including fire and toxic/hazardous release (Preuss and Hebenstreit 1990). The ponds were inundated in the San Francisco Bay region as a result of seismically-induced seiche or tsunami, causing a large discharge of contaminants into the Napa River that resulted in substantial impairment of water quality in the form of a large increase in the concentrations of salinity, suspended sediment, and other contaminants. The zone of vulnerability and secondary hazards should be identified for a complete risk management plan. Hence before conversion of new sea water inundated areas into aquaculture a thorough investigation of the area must be done with special reference to complete soil analysis and sustainable management practices have to be followed to avoid problems that shrimp farming enterprise is already facing.

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