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Assessment of Environmental Impact of Aquaculture Ponds in the Western Delta Region of Andhra Pradesh, India

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Abstract

Aquaculture is persistent and well established in the delta region of Andhra Pradesh. In recent years, the expansion of aquaculture can confer positive economic growth in the newly formed state. However, the enormous expansion of aqua ponds increases the effluents from aquaculture contains a variety of chemical compounds that could cause negative impacts when released into the environment. This paper presents the effect of un-engineered aquaculture on the environment in the delta region of Andhra Pradesh. The rate of expansion of aquaculture practice in the delta region has been done by using remote sensing and geospatial information system. An experimental investigation was carried out for both soil and water samples collected in the aquaculture ponds, to evaluate the water quality parameters, soil characterization, and soil-contaminant interaction. Based on the geospatial data and field survey, the aquaculture practice in the delta region of Andhra Pradesh was intensive and extending towards the northeast from the southwest. In between 2016 and 2020, aquaculture practice was significantly increased by 6.08%. Moreover, water quality parameters and pond bottom soil show a higher concentration of the ammonia and nitrates. Further, aquaculture leachate may interact with the subsoil and have a negative impact on soil mineralogy and hydraulic conductivity. Extensive experimental data and field surveys revealed that adequate guidelines should be needed to control the pollution load on the ecosystem.

I. Introduction

Since the 1990s, there is a major concern about the environmental aspects particularly in the landfills of both municipal solid waste and hazardous waste, mine tailings, slurry ponds, ash ponds, oil spills, radioactive wastes, chlorinated pesticide waste dumps, agriculture, and aquaculture contaminants (Chofqi et al. 2004; Sunil et al. 2008; Datta, 2012). Ever since the implementation of the engineered landfills emerged in every city with improved designs. However, there are no regulations or environmental designs in case of the chemical wastes or residues generated from the aquaculture and agriculture practices (Jayanthi et al. 2018).

In recent years, there is a significant increase in the demand for food products due to the rapid increase of population in many countries, especially in India. Further, to meet their requirements, agriculture and aquaculture practices dramatically increase production and culture expansion (FAO, 2016). However, the rapid expansion of aquaculture in developing countries leads to an impact on the environment due to poor quality control during and after the construction of aquaculture ponds (Ahmed and Lorica, 2002). The subject of aquaculture is an interdisciplinary platform to deal with; it involves biology, chemistry, environmental engineering, and soil mechanics (Edwards, 2015; Wu and Song, 2021). The main problems associated with the aquaculture ponds were seepage of contaminated water from the pond embankment, leaching of contaminated water into subsoil, improper diversion of contaminated water into drains, and filtration or separation of organic matter and effluents before draining out of contaminated water into canals (Cao et al. 2007; Islam and Yasmin, 2017).

Geotechnical engineers have a lot of aspects to deal with and develop a sustainable aquaculture pond. Geo-environmental aspects of aquaculture to be taken care of as like the revolutionary development have been taking place in recent time in the engineered landfills. In aquaculture practice, regular feed to shrimp includes zinc, phosphorous, calcium, sodium, potassium, and magnesium apart from probiotics (Phillips, 2000; Paez, 2001). The encroachment of contaminated aquaculture ponds at the end of the crop has released both organic matter and diluted minerals and chemicals (Lai et al. 2018). The main contamination of water takes place due to the excess feed and effluents generated by the aquatic shrimp (Islam et al. 2004). Further, increases the nitrates and ammonia concentration in the pond. The intensity of aquaculture practice discharges large quantities of untreated wastewater, which contains organic matter, a high concentration of chemicals, planktons, antimicrobial agents, minerals, and antibiotics (Rico et al. 2012). This discharged aquaculture affects the yield and quality of the adjacent agriculture fields. Also, freshwater bodies such as irrigation canals, drinking water ponds were polluting. Unmanaged or un-engineered culture practices possess ecological impacts occurs: (i) oxygen deficiency due to dissolved organic matters, (ii) formation of algae blooms due to accumulation of organic nutrients like nitrogen and phosphorus, further creating high biomass in the surface water, (iii) unmanaged handling of residues from aquaculture causes serious problems for human health, flora and fauna, ecosystem, and economic development. In this regard, some research has been done based on the effect of environmental due to intensive aquaculture, and a brief account of the results is presented below:

Jayanthi et al (2018) reported that the intensive aquaculture practices in India cause a reduction in the mangroves, the threat to the environment, and change in land-use patterns. The report results conclude that aquaculture practices should be monitored, and strict environmental regulations need to be implemented for a better sustainable environment. Jayanthi et al (2006) had done a case study on the effect of aquaculture practices on the Kolleru lake, which is one of the major freshwater lakes in India. However, in the last decade due to intensive aquaculture practices (increased area of aquaculture is 99.74 square kilometers) in that region caused severe environmental impact on the lake ecosystem. Based on the data analysis suggests that, in the present scenario globally, protecting freshwater bodies is much needed for future generations.

Jana and Jana Santana (2003) reported that intensive aquaculture practices reduce the yield of the agricultural crops adjacent to the aquaculture bodies due to the effluents and salinity water. The wastewater should not be directly allowed into canals because there is a need of a sedimentation process to settle dissolved solids. And using antibiotics in aquaculture is human hazardous because their presence in water will be available for up to six months. Piedrahita (2003) reported that aquaculture practice can generate varieties of chemicals and minerals which creates a negative impact on the environment. There are therefore proper guidelines that should be needed before assessing the impact of aquaculture practices on the environment. This rapid phase expansion of aquaculture and its environmental impact grabs attention worldwide is given in recent years (Eng et al. 1989; Nhu et al. 2016; Bhavsar et al. 2016). Globally many countries such as Bangladesh, Thailand, China, Mexico, Vietnam, and including India are facing environmental issues with un-engineered aquaculture (Paez et al. 1998; Abdullah et al. 2017). Moreover, in Thailand, the Thai government banned inland shrimp culture due to concern about the environment (Eng et al. 1989; Szuster, 2006). Aquaculture practices impart great influence on the environment, many aquatic species presences were migrating and disappearing. And freshwater bodies are being polluted with the contaminants from the aquaculture (Paez, 2001). In some cases, a high concentration of chemicals causes serious deterioration in irrigation or drinking water quality with further affects human health. However, to date, only a few research works published in India regarding the environmental aspects of aquaculture ponds.

This study presents the questionnaire and topographic survey in the western delta region of Andhra Pradesh to understand the rate of expansion of aquaculture ponds and the intensity of farming. This paper also explores the water quality characteristics and soil characteristics in aquaculture ponds.

Ii. Study Area

The West and East Godavari districts (delta region) of Andhra Pradesh are located along the seacoast bounded by Longitudes of 81^{o} 38′ 32″ to 82^{o} 24′ 75″ and Latitudes of 16^{o} 71′ 07″to 16^{o} 98′ 91″ (Geographic Lat/Lon WGS 84 projection). It covers an area of about 20547 square kilometres and an important river Godavari passing from these districts and merges into the Bay of Bengal. The formation of the delta region is based on thousands of year’s erosion and transportation sediments from the river Godavari. West Godavari district is having abundant waterbodies and drains connected with Kolleru lake, Yerracalva, Thammileru, and Ramileru. Drains with an area of 409km, 351km, and 1513km of the major, medium, and minor drains respectively. The soil profile of the delta region mostly covers layers of black cotton soil and sands; the sand aquifer in this region varies 10 to 15 meters below the ground level. Groundwater level ranges from 0 to 3m, 3 to 8m, and more than 8m are 15%, 27%, and 58% of district area respectively. In the early 2000s, agriculture especially paddy is the major crop in Andhra Pradesh and ranks first in the country for the highest production of rice (Adusumilli and Laxmi, 2011). After state bifurcation of A.P in the year 2014, aquaculture replacing agriculture was pervasive and entrenched into most of the delta region. These new ponds have a good network of canals and lakes, facilitating the water source and the diversion of crop end contaminated water into the irrigation canals; however, the extent of the environmental impact was not known (Jayanthi et al. 2018). Western delta region bounded in between the river Godavari, Upputeru, and Bay of Bengal (Figure 1). It covers an area of 3042 square kilometres and has a potential canal and drain network of 16.82 square kilometres.

Iii. Aquaculture Scenario In Western Delta Region

Development of newly formed state Andhra Pradesh after state bifurcation have many urgent needs, which can be the use of natural resources, earnings from exports, more employment, and a better living environment. In the 1990s, in Andhra Pradesh, aquaculture was one of the sources of the livelihood along with many other cultures. Mainly fishponds are common and only a few shrimp ponds (tiger shrimp) are in practice during the 1990s and early 2000. Recently, the Penaeus vannamei shrimp culture has emerged with a low disease rate and high production. After state bifurcation in the year 2014, the Andhra Pradesh government has relaxed the laws to construct new aquaculture ponds for the state economic growth, which leads to the large expansion of aquaculture ponds in the western delta region. Both fish and shrimp species production increased, and inland aquaculture was targeted as a major source for state development. Many lake-based sediments and aquaculture fields were converted for aquaculture by the construction of embankments. In recent years western delta region of Andhra Pradesh has emerged as a heartland of shrimp and fish production with 1.15 million metric tonnes in the year 2019 (Fisheries department, Government of Andhra Pradesh, 2020).

3.1 Questionnaire and quantitative survey

A structured questionnaire survey and field survey has been conducted in 30 villages among the aquaculture farmers, feed distributors, laboratory technicians, and aquaculture processing industrialists to understand and assess the intensity of framing and their consequences. The questionnaires included area or size of the pond, depth of the pond, the density of seed per acre, feed usage per acre, chemicals usage per acre, number of aerations per acre, lime usage, probiotics usage, disinfectants usage, number of times water change per acre, environmental impact, and sustainability concern. Based on the questionnaire survey, the intensity of the aquaculture practice was categorized into three zones: traditional farming (zone-I), semi-intensive farming (zone-II), and intensive farming (zone-III) showed in Table 2. In the delta region of Andhra Pradesh, aquaculture mainly involves shrimp and fishponds. The individual fish tanks in the study were ranging from 10 acres to 150 acres. Although ponds were huge, the effluents were low because of less usage of chemicals, probiotics, chemicals, and disinfectants. Shrimp ponds were the major contribution of effluents because of the severe or intensive cultural practices. The shrimp ponds were operated continuously without the exchange of water for a minimum of two crops (six months). Every year, before winter and summer the sedimented water was discharged out. By the quantitative analysis, it can be stated that intensive aquaculture practices can confer a negative impact on the ecosystem. Most of the locations were fall in the severe or intensive zones. Agriculture or paddy fields were converting into shrimp ponds due to higher income-generating through aquaculture and low yield of paddy due to adjacent aquaculture ponds salinity. It was anticipated that collecting questionnaires from the authorities would not be easy without farmers' support. The results of the questionnaire revealed that no guidelines or measures were considered to make a new aquaculture pond. The survey results also reflected the no proper communication between the aquaculture framers and environmental engineers to implement the sustainable environmental advancements in aquaculture ponds, and similar trends were a witness in other regions in India (Jayanthi et al. 2018). Moreover, nowadays intensive usage of chemicals, minerals, antibiotics, and probiotics with no mentioned ingredients on the bags gives negative alarming signs towards the environment. Based on the visual examination of the bottom surface soil of the pond witnesses grey and orange colour due to the anaerobic sediment (ferrous iron). In most of the ponds in the delta region of Andhra Pradesh, before starting a new crop, large amounts of urea and lime are widely used. Lime is used to reduce ammonia concentration and to decompose organic matter present in the pond bottom soil. Lime is used to increase the alkalinity, hardness, and to neutralize the acidity of the bottom soil. Moreover, aquaculture ponds are often classified based on the intensity of farming. Reported literature mentioned that pond bottom with less load of ammonia and chemicals in the bottom is being classified as younger ponds (Jayanthi et al. 2019). For a better understanding of the soil profile, physical, chemical, and biological parameters of soils should be tested. Another side, shrimp (vannamei) culture needs a brackish water environment for better yield. However, the presence of higher salinity levels in the aquaculture ponds has a significant effect on the yield of adjacent agriculture fields.

Table 1
Details of the sample collection locations in the study area and their designation

S.No	Location	Latitude (N)	Longitude (E)	Designation/ Sample Id
1	Kalla	16.5283°	81.4087°	V1
2	Kallakuru	16.5283°	81.3832°	V2
3	Kallavapudi	16.4620°	81.3881°	V3
4	Dodanapudi	16.5245°	81.3870°	V4
5	Elurupadu	16.5187°	81.3468°	V5
6	Juvalapalem	16.5190°	81.3695°	V6
7	Sessali	16.5296°	81.4334°	V7
8	Pedhaamiram	16.5443°	81.4903°	V8
9	Chinnaamiram	16.5291°	81.4911°	V9
10	Bhimavaram	16.4851°	81.4883°	V10
11	Annakoderu	16.4840°	81.4825°	V11
12	Vempa	16.4421°	81.5750°	V12
13	chilukuru	16.6232°	80.4354°	V13
14	kolamuru	16.6329°	81.4589°	V14
15	Undi	16.5864°	81.4636°	V15
16	yendagandi	16.6433°	81.5336°	V16
17	Akividu	16.5823°	81.3784°	V17
18	cherkumilli	17.0711°	81.6109°	V18
19	Kolleru	16.6629°	81.3372°	V19
20	pedakapavaram	16.6434°	81.4306°	V20
21	chinakapavaram	16.6348°	81.4162°	V21
22	palakoderu	16.5862°	81.5480°	V22
23	mogallu	16.6036°	81.5638°	V23
24	vissakoderu	16.5511°	81.5665°	V24
25	Attili	16.6885°	81.6037°	V25
26	Manchili	16.6565°	81.6062°	V26
27	Aravalli	16.6316°	81.6049°	V27
28	Eduru	16.6458°	81.5689°	V28
29	ganapavaram	16.6994°	81.4635°	V29

S.No	Location	Latitude (N)	Longitude (E)	Designation/ Sample Id
30	kesavaram	16.6810°	81.5439°	V30
31	Pippara	16.7109°	81.5418°	V31
32	Kasipadu	16.7361°	81.5514°	V32
33	Ardhavaram	16.6889°	81.5061°	V33
34	Eluru	16.7107°	81.0952°	V34
35	Kokkirailanka	16.6382°	81.2354°	V35
36	Komadavole	16.7117°	81.1258°	V36
37	Chataparru	16.6966°	81.1665°	V37
38	Chebrolu	16.8289°	81.3922°	V38
39	Unguturu	16.8230°	81.4238°	V39
40	Denduluru	16.7609°	81.1665°	V40

Table 2
Classification of aquaculture practices in the delta region of Andhra Pradesh

Description	Intensity of aquaculture practice (Penaeus vannamei)		
	Traditional	Moderate or Semi-Intensive	Severe or Intensive
Area of pond (acre)	2-5 or <	5-10	10-20 or >
Depth of water level in the pond (m)	1-1.5	1-3	1.5-4
Seed density (no/acre)	10,000 – 20,000 or <	20,000 – 60,000 or <	40,000 – 1,00,000 or <
Feed per acre (kgs)	600-850	1600-1700	2100-2200
Survival rate (months)	2-3 or <	1-3 or <	1-3 or <
No of crops per year	4 or <	3-4 or <	3-4 or <
Aeration sets per acre	1-2 or <	2-4 or <	4-5
Production per acre per crop (tons)	1-2 or <	1-5 or <	4-8 or <
Lime used per acre per crop (kgs)	5-10 or <	5-25 or <	10-50 or <
Potassium/magnesium/calcium chlorides used per acre per crop (kgs)	1-5 or <	5-10 or <	5-25 or <
No of times chemicals used per crop	2-4 or <	2-6 or <	4-8 or <
No of times probiotics used per crop	1-3 or <	2-8 or <	4-12 or <
No of times disinfectants used per crop	1-2 or <	1-4 or <	2-6 or <
Salinity range (ppm)	0-4	4-6 or <	5-9 or <
Water exchange per year	3-5 or <	3-5 or <	2-3
Environmental impact	Moderate	High	relative
Sustainability concerns	Moderate	Low	relatively low

3.2 Land use and land cover

The topography survey was carried in the western delta region of Andhra Pradesh using the cloud free data collected from the freely available USGS earth explorer (sentinel 2). The data was acquired for July 2016, July 2017, Jan 2019, and July 2020. The classification was done based on ArcGIS 10.6 with the help of satellite data collected from the source. The area of each pixel was computed using the raster unique data values. In classification, changes in the pixels were evaluated by the change detection matrix. To know about better accuracy of the classification, field examination has been done in the 64 sites to understand the field scenario. the overall accuracy of classification was more than 94.5%. Maps of 2016, 2017, 2019, and 2020 were used to quantify the changing land-use patterns. Few studies have been done in the past to know the landscape transformation in Andhra Pradesh especially in the Kolleru basin and Nellore region (Jayanthi et al. 2006; Jayanthi et al. 2019). In this study, the land use and land cover classification consisted of aquaculture ponds, croplands, barren lands, and urban lands with a total western delta area of 3012.45 sq.km. The land-use and land cover classification results were shown in Figure 3. The land-use patterns were dominated by aquaculture throughout this study. Aquaculture ponds (including shrimp and fishponds) are practiced in this region was occupied with an area of 702.22 sq.km in the year 2016 and was increased by 6.08% from 2016 to 2020. Moreover, most of the aquaculture area is under catchments of Undi canal, Venkayya canal, Narsapur canal, and Gostani canal with 32.4%,26.6%, 18.3%, and 13.6% respectively in the year 2020. A peer glance in the past study reveals that, before state bifurcation of Andhra Pradesh, from 1988 to 2013, land use converted to aquaculture ponds was 13524 hectares (Jayanthi et al. 2018). From the current study after state bifurcation, from 2016 to 2020, the land use converted to aquaculture ponds was 3988 hectares (nearly one-third of the aquaculture ponds conversion from 1988 to 2013). The aquaculture intensity was expanding towards the northeast from the southwest. Clear rapid urbanization is also apparent in the delta region, due to the increase in the aquaculture processing industries, feed stores, and laboratories. The covered area of drains and their sediments did not show any considerable area changes with a rate of loss of 0.2–0.3% each year because of the erosion of canals or ponds embankments. This is due to the no stringent regulations for converting agricultural lands into aquaculture ponds. So, an increase in the aquaculture practices in the delta region leads to a negative impact on the vegetation or croplands. This comparative analysis shows that future aquaculture practices face severe conflict with the irrigation waterbodies and habitations. So, adherence to sustainable regulations is much needed for a sustainable environment and to avoid water conflicts.

Iv. Impact Of Aquaculture On Environment

4.1 Water quality characteristics

Physico-chemical characteristics of the study area such as pH, total dissolved solids (TDS), electrical conductivity (EC), salinity, total ammonia (TA), dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), PO_4, SO_4, NH_3, NO_2, and NO_3 were determined according to the standard Indian procedures and the entire test results shown in Table 3. The pH of the water samples was ranging from 7.4 to 9.4 indicating that a higher alkaline environment and not suitable for drinking water. The EC values are not within the maximum permissible limit. The TDS values were fall out of the standard limits (500 mg/l), only 5% of tested samples were within the desirable limits. TDS generally comprises particulate organic matter and inorganic salts, high values of TDS were seen in the intensive farming zone. This can be attributed due to the particulate matter from the uneaten feed and shrimp effluents. BOD_5 represents the organic pollutants in the water, the average values in this study ranges from 0.6 to 14.2 ppm and were reportedly higher in the intensive zone practice.

Table 3
Physico-chemical characteristics of aquaculture pond water

Sample Id	p^H	TDS (ppm)	EC (µs/cm)	Salinity (ppt)	T.A. (ppm)	PO_4 (ppm)	SO_4 (ppm)	DO (ppm)	BOD_5 (ppm)	COD (ppm)	NH_3 (ppm)	NO_2 (ppm)	NO_3 (ppm)
V1 (a)	8.2	360	320	5	84	Nil	Nil	4.0	12.6	36	6.14	0.04	1.21
V1 (b)	8.7	850	1055	14	215	Nil	Nil	4.0	12.6	38	2.20	0.04	1.21
V2 (a)	8.5	6200	8900	8	180	Nil	0.25	5.9	10.6	76	1.48	2.18	9.07
V2 (b)	8.2	180	230	10	84	Nil	Nil	5.3	12.6	36	2.20	0.04	1.21
V3 (a)	9.4	3240	4500	8	140	Nil	Nil	3.5	14.2	84	4.15	0.85	8.08
V3 (b)	8.1	540	1400	7	320	Nil	Nil	5.5	13.6	32	5.30	1.20	4.62
V4 (a)	8.8	420	451	4	160	Nil	Nil	4.6	12.8	48	1.5	0.03	4.38
V4 (b)	8.4	2340	5675	2	180	Nil	Nil	3.5	11.4	78	0.60	0.48	6.60
V5 (a)	7.8	180	465	0	160	0.30	1100	5.0	3.6	36	1.24	0.05	11.4
V5 (b)	7.4	320	580	0	180	0.1	Nil	4.6	2.8	48	1.50	0.33	4.38
V7 (a)	8.3	2400	8350	2	260	Nil	Nil	4.5	11	36	2.55	1.26	4.48
V7 (b)	8.7	4200	58000	8	430	Nil	Nil	5.5	12.4	88	3.15	0.17	4.16
V8 (a)	8.2	7240	11200	6	232	0.1	1778	5.8	10.6	45	3.47	0.92	8.84
V8 (b)	9.4	760	1154	5	400	Nil	Nil	5.0	12.4	38	5.02	1.24	5.15
V9 (a)	8.6	530	890	4	310	0.15	815	6.0	11	60	1.15	0.88	10.6
V9 (b)	7.6	8700	53000	4	132	0.3	312	9.2	11.3	48	4.4	0.06	2.51
V10 (a)	8.5	4140	760	4	210	0.15	860	2.0	15	78	2.62	0.08	2.51
V10 (b)	8.5	1200	8000	11	245	Nil	Nil	4.5	3.4	36	2.4	0.45	11.6
V19 (a)	8.4	250	460	7	195	Nil	Nil	5.5	12.6	45	0.48	0.07	10.2
V19 (b)	7.4	520	850	2	170	Nil	Nil	4.9	0.6	64	0.97	0.04	5.75
V27 (a)	8.2	1100	2180	11	300	Nil	Nil	5.3	2.8	60	5.09	1.29	6.15
V27 (b)	7.8	1500	2200	2	170	0.4	0.15	5.5	2.8	64	1.08	0.05	13.1
V28 (a)	8.4	450	780	4	170	Nil	Nil	4.0	15	65	0.18	1.24	4.66
V28 (b)	8.4	3200	6500	8	170	Nil	Nil	5.5	4.5	65	1.66	2.16	5.45
V34 (a)	8.3	2300	3400	4	160	0.3	716	7.3	5.3	32	1.23	0.33	4.53
V34 (b)	8.4	3400	5450	0	315	Nil	Nil	5.5	11.6	78	1.85	1.44	11.6
V35 (a)	8.2	8000	12000	8	280	Nil	Nil	3.3	10.4	65	1.24	0.05	7.15
V35 (b)	7.8	3600	52000	13	170	Nil	Nil	5.0	5.3	32	0.54	2.18	9.07
V39 (a)	8.5	5000	10080	9	185	0.43	Nil	3.0	14.5	88	1.23	0.33	4.53
V39 (b)	8.5	8200	11800	10	500	Nil	Nil	5.3	2.8	60	5.59	2.39	9.32

Seasonal changes (post-monsoon and pre-monsoon) in water characteristics are reflected in the study area. The total ammonia and BOD_5 concentrations were not within the Indian standard limits during post-monsoon. This could be due to the higher temperatures in summers allows more chemical and biological reactions. Other hand, there is no significant change in the TDS values during post-monsoon and pre-monsoon. This is due to the excess particulate matter such as uneaten feed, shrimp waste, and poultry manure generated from the aquaculture ponds remains same. Ammonia is the major concern with the higher concentrations in the ponds falling in Zone-III. Further, the higher load of ammonia leads to a reduction of dissolved oxygen.

4.2 Aquaculture Pond subsoil characteristics

In general, the construction of new ponds involves excavation of surface soil and used as a fill material for earthen embankments. Most of the aquaculture ponds are normally on clayey deposits with a low amount of organic matter and nutrients at the initial stage of the crop. After two or more crops in the new pond, surface soil exposed with aquaculture effluents may increase the nutrients, organic matter, particulate matter, and phytoplankton blooms. This may further influence the physico-chemical characteristics and geotechnical characteristics of the surface and subsoil. This is also reflected in the behaviour of aquaculture sludge leachate and clays interaction. In this study, in dried aquaculture ponds after crop, soil samples were collected with the help of PVC pipe with a diameter of 15cm and length of 1.8m was penetrated and collected undisturbed soil samples. The samples were tested for physicochemical characteristics, geotechnical properties, and aquaculture leachate and clay interactions.

4.2.1 Physico-chemical characteristics

Table 4 shows the physicochemical test results of soil samples collected from the soils exposed with various intensities of aquaculture sediments. From Table 4, by comparison, it was clear that zone-III soils exhibited higher contents of potassium and phosphorus. This is due to the uneaten feed (phosphorus) strongly adsorbs to the clay. Moreover, aquaculture pond soil adsorbed phosphorus will not release into the water due to the highly insoluble behaviour of phosphorus. In the study area, test results exhibit cations trend was Ca^{2+} > Na^{+} > Mg^{2+}> K^{+}. This could be due to the excessive lime, potassium, and magnesium usage in the ponds. The discharged effluents from the aquaculture ponds were having a higher concentration of nutrients leads to eutrophication, higher contents of salinity reduce the vegetation growth, and higher concentrations of chemicals lead to ecological imbalance.

Table 4
Physico-chemical characteristics of aquaculture pond subsoil

Zone	Village	p^H	TDS (ppm)	EC (µs/cm)	TOC (%)	TN (kg/acre)	P (kg/acre)	K (kg/acre)	S (kg/acre)	Na (ppm)
Intensive (III)	V1	8.2	2.5	5.1	1.45	116	507	570	245	238
	V2	8.0	4.2	2.2	2.28	1077	472	432	230	215
	V3	7.7	2.9	2.5	3.98	125	491	848	218	178
	V4	7.5	2.1	5.4	3.72	32	484	564	156	165
	V5	7.4	1.7	2.3	2.99	118	490	388	165	182
Semi-intensive (II)	V7	7.2	1.8	2.7	2.22	188	377	375	154	174
	V8	7.2	1.6	2.4	1.12	85	257	415	145	163
	V9	7.8	1.2	1.8	1.18	102	186	345	205	162
	V10	7.7	0.5	0.7	1.45	78	154	386	88	125
	V19	7.6	1.1	1.9	1.85	84	132	243	106	128
Traditional (I)	V27	7.6	1.7	2.6	0.84	95	195	334	115	134
	V28	7.6	1.2	2.3	0.74	68	88	355	125	185
	V34	7.4	1.2	1.8	0.84	76	85	245	155	215
	V35	7.0	1.4	1.3	1.05	82	157	175	145	113
	V39	7.4	1.2	1.7	1.16	82	165	235	165	151

4.2.2 Geotechnical properties

Table 5 shows the entire test data of the plasticity characteristics and hydraulic behaviour of the soil samples collected in the aquaculture ponds. All the tested samples were expansive clays possessing intermediate to high compressibility. Free swell index of the samples ranging from 55 to 145%, zone -I samples was exhibiting higher free swell index values compared with Zone-II and Zone-III. This could be due to the presence of lime content in the aquaculture water that reacts with the clayey soil. Further, due to the flocculation of particles and ion exchange hydraulic conductivity also improved.

Table 5
Plasticity and hydraulic behaviour of aquaculture pond clays

Zone	Sample Id	Liquid limit, LL (%)	Plastic limit, PL (%)	Plasticity index, PI (%)	FSI (%)	Hydraulic conductivity (cm/sec)
Intensive (III)	V1	65	21	44	85	$3.2x10^{-5}$
	V2	60	24	36	80	$5.1x10^{-5}$
	V3	68	20.5	47.5	75	$6.8x10^{-6}$
	V4	44	18	26	55	$5.5x10^{-5}$
	V5	54	21.5	32.5	85	$3.6x10^{-5}$
Semi-intensive (II)	V7	62	32.5	29.5	75	$2.8x10^{-6}$
	V8	64	33	31	55	$5.6x10^{-7}$
	V9	84	33.5	50.5	130	$6.9x10^{-7}$
	V10	64	19.5	44.5	80	$4.4x10^{-6}$
	V19	84	29	55	120	$4.5x10^{-6}$
Traditional (I)	V27	80	30	50	105	$4.2x10^{-7}$
	V28	89	31	58	130	$4.6x10^{-6}$
	V34	82	32	50	114	$5.0x10^{-6}$
	V35	76	34	42	145	$5.5x10^{-7}$
	V39	88	25	63	136	$4.4x10^{-7}$

By comparison, Zone-III and Zone-I, plasticity behaviour of the Zone-III pond bottom clays exhibits low plasticity behaviour due to the cation exchange of clays and aquaculture sludge. The observed trends are in agreement with the Khodary et al. (2020) that leachate concentration of industrial solid waste landfill shows that reduction of plasticity behaviour of clays due to the free ions such as K^+, NH^{4+}, Ca^{+2}, and Na^+ replaced the cations of the clay surface (double diffusion layer) and further improves the pores between the particles. Moreover, monovalent cations contribute to the reduction of the double diffusion layer of clays and adsorbed water.

Hydraulic conductivity is high in the zone-III because of the flocculation and agglomeration of particles and due to ion exchange of clay particles and lime content.

4.2.3 Aquaculture sludge leachate and clays interaction

The cation exchange capacity (CEC) values of the clays were vital in the selection of clays as a water barrier material. In this study, CEC values were determined by using the test procedure reported by Rhoades (1983) and results were shown in Table 6. The CEC values of clays blended with the aquaculture leachate were significantly decreased due to the exchange of ions. CEC values of the virgin clays and clays blended with the aquaculture sludge leachate were shown in Table 6. On the other hand, there is a relation between the CEC values and swelling behaviour of clays, it is safer to select clays with lower CEC values (<20 mEq/100gm) for the foundation material, pavement subgrade material, and backfill material (Yu et al. 2014). Clays and aquaculture sludge leachate interaction contributes to the exchange of ions such as NH^{4+}, K^+, Ca^{+2}, and Na^+ in the clays. So, clays exposed with aquaculture leachate show a significant effect on the clay mineralogy. This can further influence the double diffusion layer and surface forces or attractions of clays. Ions of NH^{4+}, K^+, Ca^{+2}, and Na^+ were significantly increased with the increasing aquaculture sludge leachate concentration. Apart from the effect of aquaculture leachate and CEC, understanding the combined effect of CEC and swelling behaviour of clays is advantageous for construction activities. Moreover, due to the proportionality between the cation exchange and permeability of clays, it is required to understand or monitor the groundwater quality for a sustainable environment.

Table 6
Effect of aquaculture leachate on clay minerology

Condition	Plasticity Index, %	CEC, mEq/100g	Ammonia, mEq/100g	Potassium, mEq/100g	Sodium, mEq/100g	Calcium, mEq/100g
Clay with no leachate exposure	59	52.55	0.04	3.27	0.22	31.35
Clay with Zone-III aquaculture leachate exposure	54	42.67	18.35	15.44	7.45	40.18
Clay with Zone-II aquaculture leachate exposure	51	34.82	39.54	24.17	32.88	42.15
Clay with Zone-I aquaculture leachate exposure	43	26.44	52.44	42.87	51.14	44.27

V. Conclusions

In this comprehensive study, aquaculture practices in the western delta region of Andhra Pradesh, are demonstrated and efforts are made to assess the aquaculture practices and their impact on the environment. To better understand the problems associated with intensive farming, questionnaire survey in the field, a topography survey using GIS, extensive experimentation on water and soil samples, and soil and aquaculture leachate interactions were studied. The following conclusions were drawn:

Questionnaire survey results show most of the locations in the western delta region fall in the severe or intensive farming zone. The growing extent of aquaculture ponds and operated continuously without exchange of water for a minimum of two crops with a higher concentration of chemicals and minerals is worrisome, needs proper guidelines or attention to make a sustainable ecosystem.

Land use and land cover results during 2016 and 2020 revealed that dynamic changes were witnessed in aquaculture ponds that have significantly increased by 6.08% (43.18 sq.km). Croplands were decreased by 7.83% (108.48 sq.km) due to the rapid increase in aquaculture ponds and urban land. despite poor laws and state economic growth concerns, croplands were converted to aquaculture ponds.

Physico-chemical characteristics of aquaculture pond waters reflect converging trends for each zone. TDS, Ammonia, DO, BOD_5, COD, PO_4, SO_4, NH_3, NO_2, and NO_3 were showing higher concentrations in the aquaculture ponds and exceeded the Indian standard limits of the irrigation water. Moreover, based on the COD and BOD_5 values, indicates the excess particulate matter, ammonia, and nutritious compounds with the intensive aquaculture farming. Finally, due to the excess chemical usage in the aquaculture pond water reflects higher potassium and phosphorus. This is due to the uneaten feed (phosphorus) strongly adsorbs to the clay.

The rapid increase of intensive aquaculture farming is inevitable and generates higher concentrations of ions NH^{4+}, K^+, Ca^{+2}, and Na^+. Further, these ions replaced the double diffusion layer of clays and reduces the surface forces and plasticity of clays. CEC values of blended clays were significantly decreased with the increase in the aquaculture leachate concentration. This is due to the exchangeable cations between the aquaculture leachate and clay surfaces. Therefore, it is needed to have good water barriers (geosynthetic membranes) and effluent purification systems to reduce the contaminants loading on the environment.

Finally, this article presents the quality data to assess the un-engineered aquaculture practices in the western delta region of Andhra Pradesh. Further, it may draw attention among practising engineers, government officials, and researchers to make a sustainable ecosystem.

Declarations

Competing interests:

The authors declare no competing interests.

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Figures

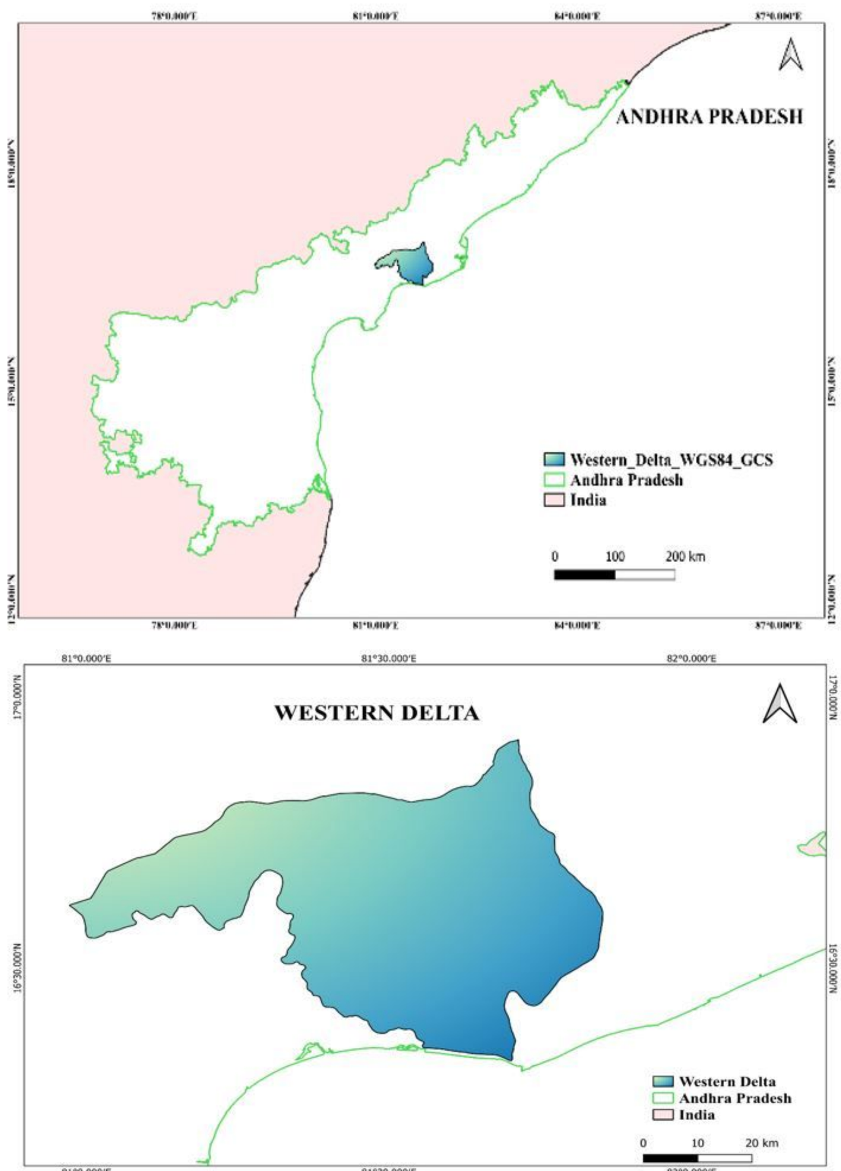

Figure 1

Western delta region of Andhra Pradesh

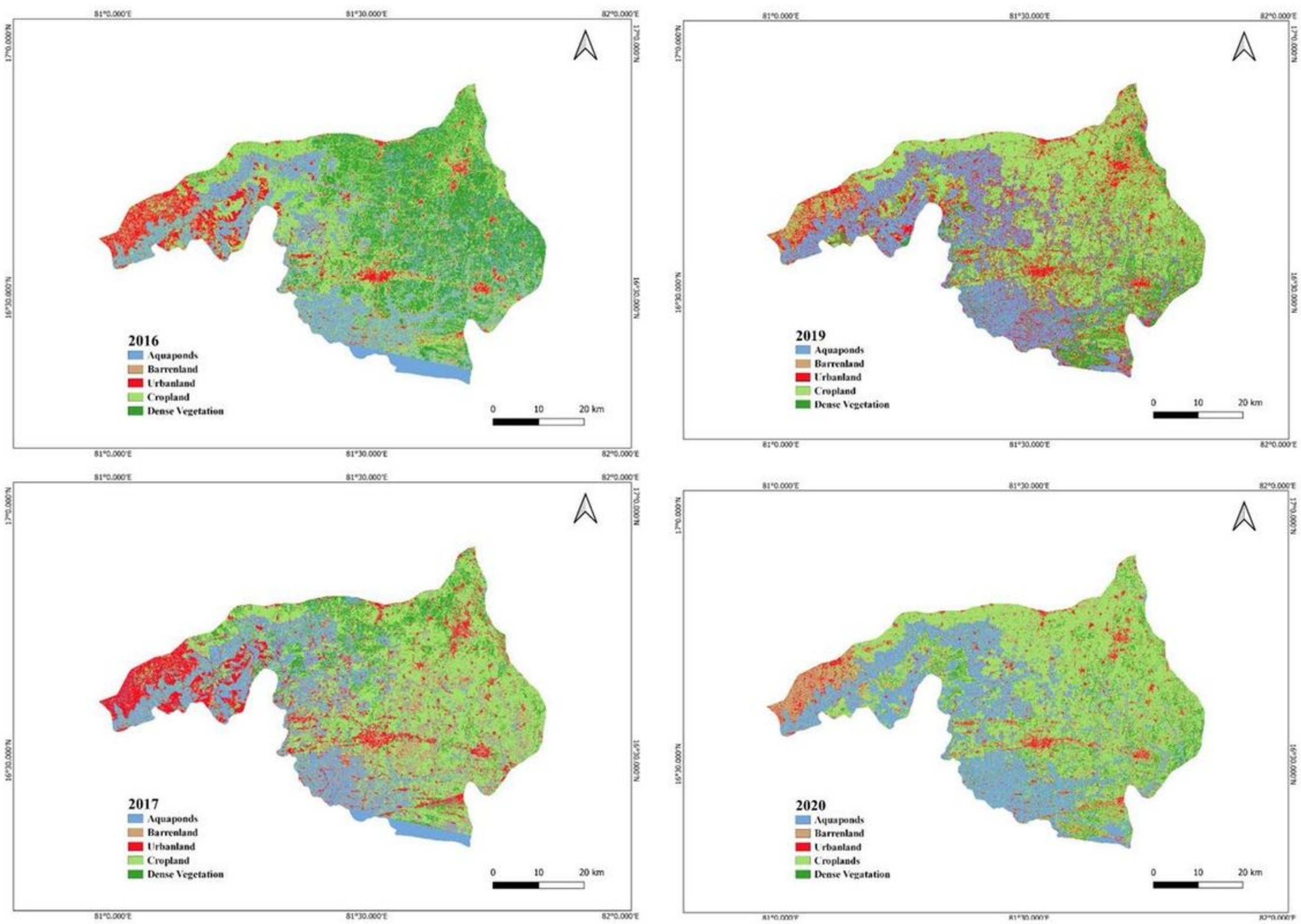

Figure 2

Land use and land cover maps of study area between 2016 and 2020

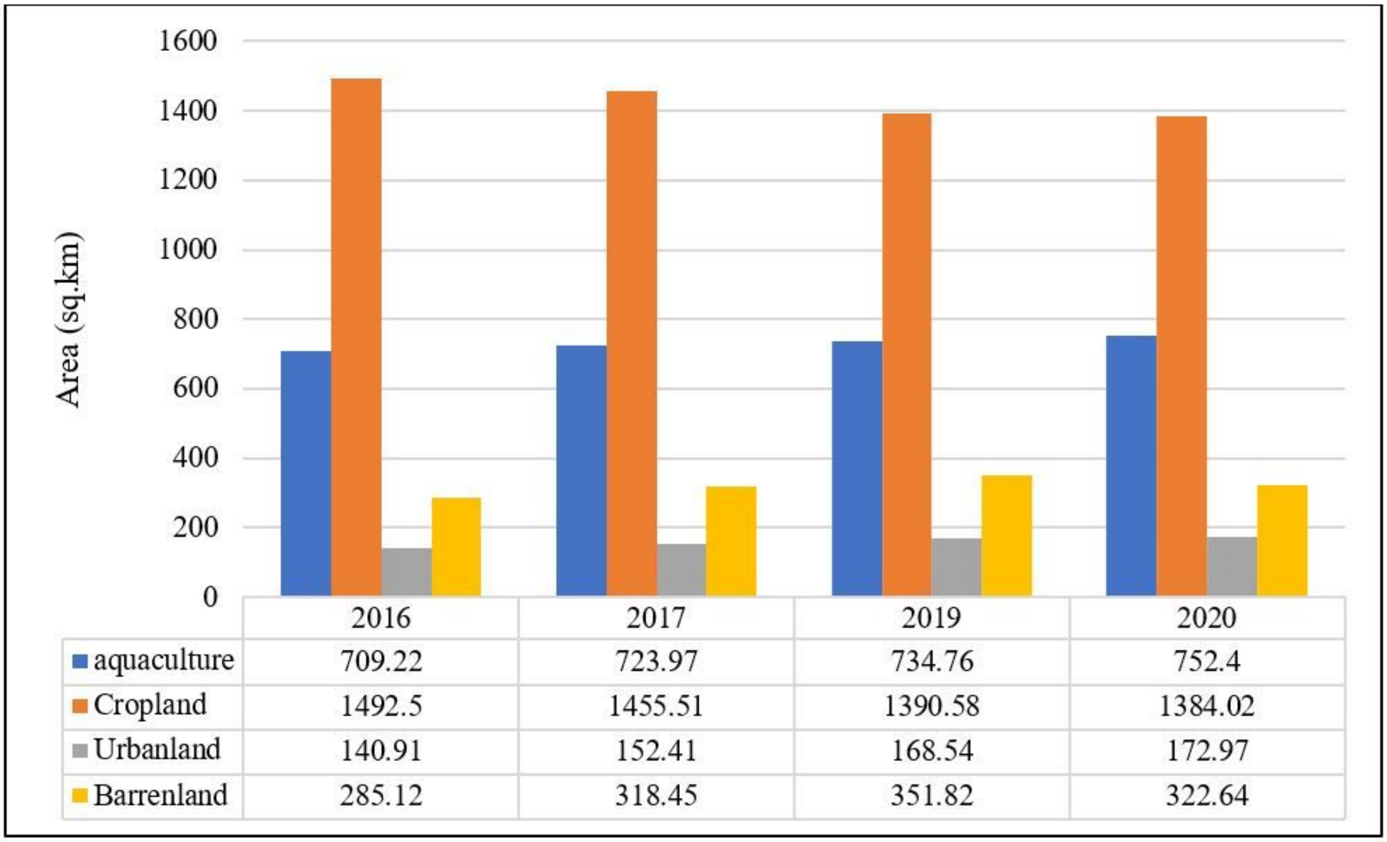

Figure 3

Land use and land cover classification of western delta region