Original Research Article

The scenario of groundwater pollution after implementation of zero liquid discharge – An agricultural economic perspective

ABSTRACT

Groundwater pollution is hard to remediate in the Noyyal river region even after the implementation of Zero Liquid Discharge process. Hence, to study the status and extent of groundwater pollution in the Noyyal river region, Tiruppur district of Tamil Nadu was purposively selected and classified into 3 regions based on the distance from the river and 120 farms were selected. Tools of analysis viz., Cost benefit analysis, Resource use efficiency and decomposition analysis were undertaken to study the status of groundwater pollution and its effect on agriculture. The results showed that intensity and severity of pollution is high in the region closer to Noyyal river (less than 1 km). Income from agriculture is also low in that region due to the use of polluted groundwater for irrigation. The study revealed that Zero Liquid Discharge ensures stoppage of industrial effluents into the river and hence, river pollution is stopped. Similarly, a suitable policy is required to revamp groundwater. Hence, the suggested policy includes water storage structures like tanks, lakes, ponds etc are to be used for groundwater recharge purpose alone.

Keywords: Groundwater, pollution, agriculture, irrigation, Noyyal river

Introduction

Water is the most important and inevitable gift of nature. It is basic need, essential for survival on earth. It is the most important requirement for humans, crops, plants, etc. If there is no water, there will be no life on earth. Water and sanitation are at the core of sustainable development (SDG 6th goal). However, all water available on earth is not fresh. The quantity of fresh water available is very less compared to the total water available on the earth. It is found that, out of total water present on the earth only 2.53 per cent are fresh. (Shiklomanov 1993). Groundwater is the second largest fresh water source and it is said to be the very good source for drinking and irrigation because of the purification properties of the soil.

Groundwater satisfies 40 per cent of the world's irrigation requirement and in India groundwater provides 60 per cent of total irrigation supply. India is the largest consumer of groundwater (Jain et al. 2021). Groundwater irrigation has gained momentum from 1965, after the introduction of tube well technology. Area irrigated by groundwater has increased from 29 % to 60 % in India. (Jain, Kishore, and Singh 2019). From this it is clear that groundwater has become dominant source of Irrigation in India. Inspite of several importance laid on groundwater, it is being polluted in several ways which causes deterioration of quality of groundwater called groundwater contamination.

Ground water contamination is the result of polluted water infiltrating through the soil and rock and eventually reaching the ground water. (Geetha et al. 2008; Teng et al. 2018). If contaminated, the remediation process is too challenging and expensive, because of its location in subsurface geological strata (Wang et al. 2020; Su et al. 2020). The process of natural purification of contaminated groundwater may even become decades or hundreds of years. (Tatti et al. 2019)

Water pollution is due to increased urbanization, population, industrialization, intensive agriculture etc., (Li et al. 2021). The textile dyeing industry is one of the most important polluting industries in India leading to water quality loss both in surface and groundwater. (Bhatia et al. 2017; Bhatia et al. 2018). These industries polluted the Noyyal river, draining water in the Western part of Tamil Nadu, which in turn pollutes the groundwater surrounding the river till the year 2011, after which Zero Liquid Discharge principle is under practice in complete stoppage of pollution. Zero Liquid Discharge means, no dyeing waste water is to be discharged into the river instead it has to be purified and reused by the industry itself, in order to control pollution in the Noyyal river as ordered by the High Court in the year 2011. Because of this, the pollution by industries in the river was stopped.

However, groundwater pollution is still witnessed in that region. This poses negative impacts on groundwater agriculture and its economics till now. This paved the way to attempt research in this area with the following objectives.

Objectives

- To study the cost and returns, resource use efficiency of major crop cultivated and to decompose the factors affecting the gross returns of the crop in the study area
- To analyse the impact of water quality on the value of agricultural land among the sample farms through hedonic pricing method.

Design of the study

Palladam and Avinashi blocks of Tiruppur district in Tamil Nadu were purposively selected to study the present status of groundwater pollution. Among different blocks in which Noyyal flows in Tiruppur district, these two blocks occupied larger area under groundwater irrigation and hence selected.

The study area is divided into three different categories based on the distance of the sample farms from the Noyyal river, in order to find the present status of groundwater pollution, extent of pollution from the river and its impact on agriculture. The categories were less than 1 km from the river (closer region), 1-3 km from the river (middle region) and more than 3 km from the river (distant region). Under each category a quota of 40 farmers were selected randomly and hence the total sample size constitutes to 120 farmers. The study was carried out by collecting primary data.

Resource use efficiency

During the preliminary survey, coconut was found to be the predominant groundwater irrigated crop in all the three categories of the study area. Hence analysis was undertaken to study the resource use efficiency of coconut production among the sample farms. Like Karthick, Alagumani and Amarnath et al. (2013) and Jeevan, Mukhopadhyay, and Dey (2018) in this study also Cobb-Douglas type of production function analysis was employed to estimate the yield response of coconut in three different categories of sample farms to various factors of production. The production function was

$$Y = \beta_0 X_1^{\beta 1} X_2^{\beta 2} X_3^{\beta 3} X_4^{\beta 4} X_5^{\beta 5} U_i \text{ --------------------(1)}$$

Where, Y - Gross returns (in ₹./ac)

X_1, X_2, X_3, X_4 and X_5 - Value of manures (in ₹./ac), fertilizes (in ₹./ac), irrigation water (in ₹./ac), plant protection chemicals (in ₹./ac) and labour (in ₹./ac) respectively

β_0 - Constant, U_i - Error term, β_i's - Parameters to be estimated.

This equation (1) was transformed into the logarithmic form (log linear) as represented below and analysed :

$$\ln Y = \ln \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 +$$
$$\beta_6 \ln X_6 + \ln U_i \text{ -----------(2)}$$

Farms in the closer region are considered as severely affected, middle region as moderately affected and distant region as unaffected. The equation (2) was separately written for each region as follows

$$\ln Y_{CR} = \ln a_1 + \beta_{1CR} \ln X_{1CR} + \beta_{2CR} \ln X_{2CR} + \beta_{3CR} \ln X_{3CR} + \beta_{4CR} \ln X_{4CR} + \beta_{5CR} \ln X_{5CR}$$
$$+ \ln U_{CR} \text{ ---------------(3)}$$

$\ln Y_{MR} = \ln a_2 + \beta_{1MR} \ln X_{1MR} + \beta_{2MR} \ln X_{2MR} + \beta_{3MR} \ln X_{3MR} + \beta_{4MR} \ln X_{4MR} + \beta_{5MR} \ln X_{5MR} + \ln U_{MR}$ ----------(4)

$\ln Y_{DR} = \ln a_3 + \beta_{1DR} \ln X_{1DR} + \beta_{2DR} \ln X_{2DR} + \beta_{3DR} \ln X_{3DR} + \beta_{4DR} \ln X_{4DR} + \beta_{5DR} \ln X_{5DR} + \ln U_{DR}$--------------(5)

Where,

Y_{CR} = Average gross returns of closer region farms (₹./acre)

Y_{MR} = Average gross returns of middle region farms (₹./acre)

Y_{DR} = Average gross returns of distant region farms (₹./acre)

a_1, a_2, a_3 are the intercepts of closer, middle and distant region respectively.

X_{nCR} = Independent variables of closer region farms

X_{nMR} = Independent variables of middle region farms

X_{nDR} = Independent variables of distant region farms

Decomposition analysis

Decomposition of output change is a technique used to factor out the effects of technology or an environmental damage or any other impact on production. (Pouchepparadjou, Kumaravelu, and Achoth 2005).

Taking the difference between (3) and (5) we get

$$\ln (Y_{CR} / Y_{DR}) = \ln (a_1 / a_3) + [(\beta_{1CR} - \beta_{1DR}) \ln X_{1DR}] + [(\beta_{2CR} - \beta_{2DR}) \ln X_{2DR}] + [(\beta_{3CR} - \beta_{3DR}) \ln X_{3DR}] + [(\beta_{4CR} - \beta_{4DR}) \ln X_{4DR}] + [(\beta_{5CR} - \beta_{5DR})] \ln X_{5DR}] + [\beta_{1DR} \ln X_{1DR} / X_{1CR} + \beta_{2DR} \ln X_{2DR} / X_{2CR} + \beta_{3DR} \ln X_{3DR} / X_{3CR} + \beta_{4DR} \ln X_{4DR} / X_{4CR} + \beta_{5DR} \ln X_{5DR} / X_{5CR}] + (U_{CR} - U_{DR}) \text{ ---------------(6)}$$

Equation (6) approximately apportions the difference in yields of coconut per acre between unaffected farms and severely affected farms. First term on right hand side indicates the percentage change in yield due to a shift in scale parameter and the next term measures the effect of changes in slope parameters (output elasticity). These two terms sum up to the total of unaffected farms effect. The third term measures the contribution of changes in input levels to changes in output. The last term is a random term. Similarly, differences between moderately affected and unaffected farms were also calculated.

Hedonic Pricing Technique

The hedonic pricing method is used to estimate economic values for ecosystem or environmental services that directly affect market prices (Yuvasakthi and Kumar 2017). In present study, hedonic model is used to find out the value of agricultural land in relation to gross returns, scale of pollution intensity, distance of land from polluted source and main road. The following regression model was used.

$$VCL = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + u_i \text{ ---------------(9)}$$

Where, VCL - Value of agricultural land (in ₹./ac)

X_1 - Farm income (in ₹./ac)

X_2 - Scale of pollution intensity (unaffected - 1, moderately affected - 2, highly affected - 3)

X_3 - Distance between land and polluted source(river) (in metres)

X_4 - Distance between land and main road (in metres)

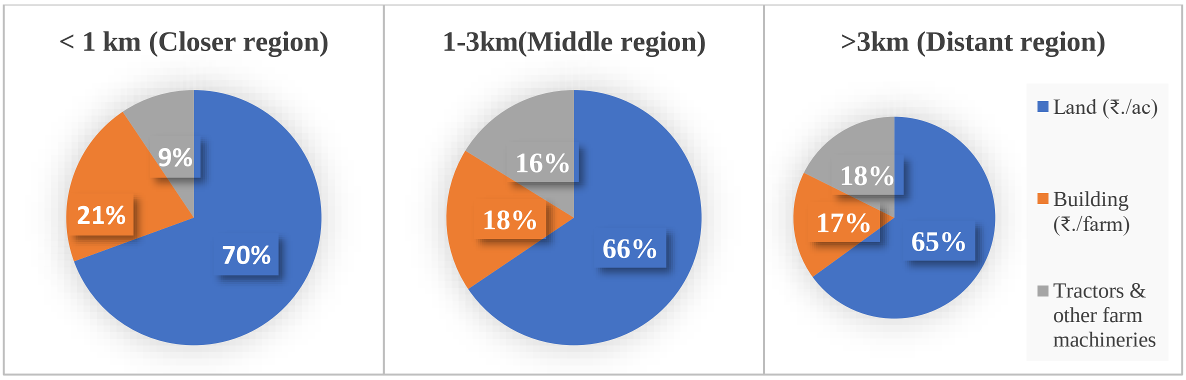
β_0 - Regression constant

β_1 to β_4 - Regression coefficient

u_i - error term

Results and discussion

Figure – 1. Asset position of the sample farms



It could be inferred from the figure – 1, that the value of land occupies the major portion of the asset. It shares more than 65.00 per cent to the total in all the three regions. However, the value of land per acre was low in closer region (₹. 1718761.47) compared to middle region (₹. 1956547.19) and distant region (₹. 2093885.81). This variation may be due to the difference in intensity of pollution, which affects the value of land. This variation in the value of agricultural land was analysed using hedonic pricing technique and presented at the last. The value of building was almost similar among the three regions, no much deviation in value but on comparison to the total share in percentage, it varies. The value of farm machineries owned was found doubled in middle region (₹. 483565.21) compared to closer region (₹. 233000.00) whereas, in distant region it is still higher (₹.568869.56). This indicates that the agricultural activity is very low in closer region compared to other two regions. The reason is that, the closer region becomes less suitable for agriculture because of the use of polluted groundwater for irrigation which may result in land degradation.

Figure – 2. Average livestock possession of the sample farms (in No.)

Figure - 2. Average livestock possession of the sample farms (No.)

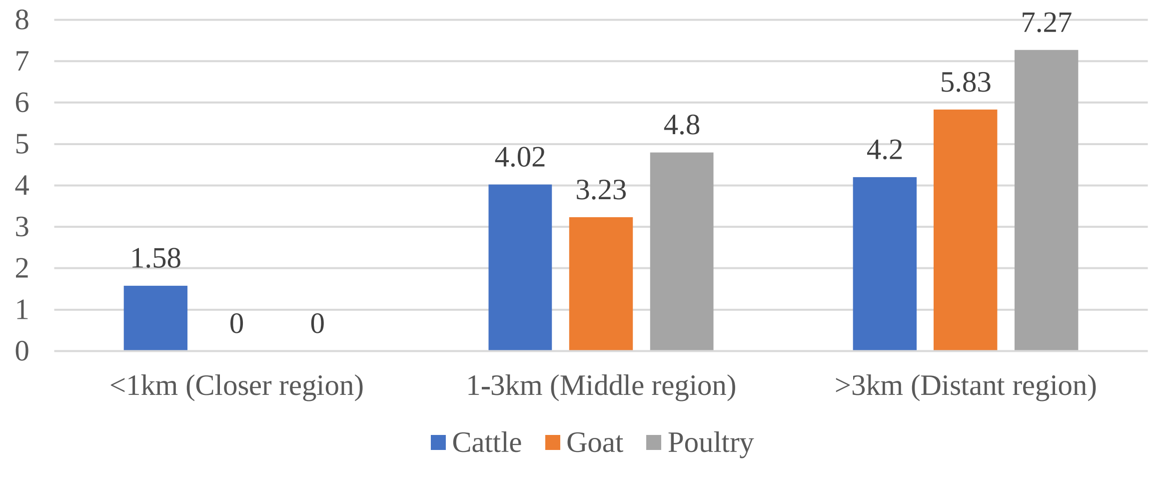


Figure – 2, show the average livestock possession of the sample farms. It could be inferred that the average number of cattle was found to be very low in closer region having one cattle per farm and no goat or poultry. Cattle possession shows the unfavourable condition of agriculture in the closer region. However low possession of livestock was also due to absence of grazing land. Closer region is a place of town, occupied by large number of houses and industries. Hence causing decline in livestock possession.

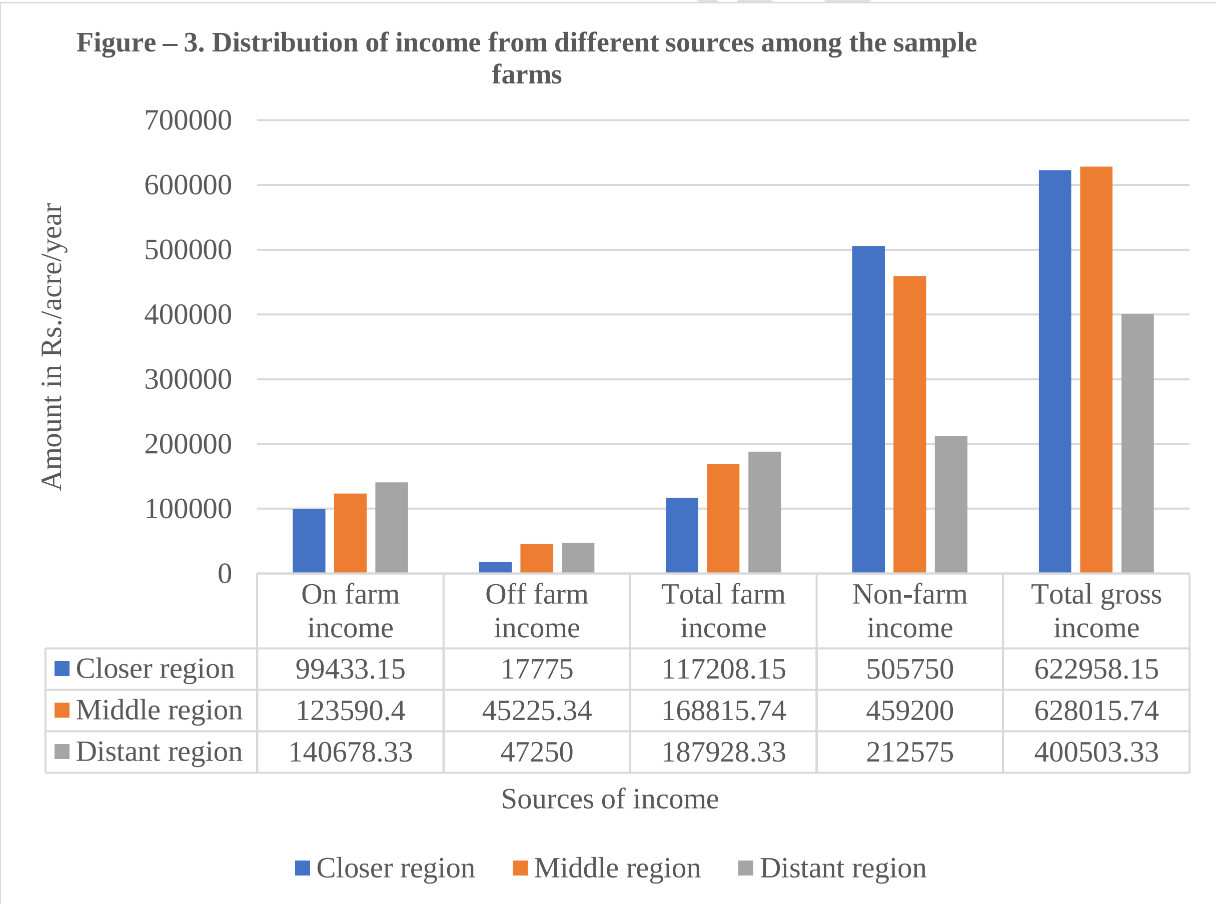
Table – 1. Changes in the cropping and occupation of the study area

S.No	Particulars	Farm location from Noyyal river		
		<1km (Closer region)	**1-3km (Middle region)**	**>3km (Distant region)**
1	Predominant irrigated crop	Coconut	Coconut, Banana	Banana, Coconut
2	Predominant rainfed crop	Sorghum	Sorghum	Groundnut, Sorghum
3	Predominant occupation	Powerloom, shops	Powerloom, farming and fabrication	Farming and fabrication

Coconut is found to be the predominant irrigated crop in the study area followed by Banana. The predominant rainfed crop is sorghum in the study area followed by groundnut.

However, Banana is not cultivated in the closer region, it is cultivated only in middle region and distant region. The reason may be due to high intensity of polluted groundwater which is unsuitable for banana growth in the closer region. Similarly, groundnut is not cultivated in closer and middle region as rainfed crop, cultivated only in distant region. The reason may be due to land degradation by use of polluted water for irrigation causing unfavourable condition for groundnut cultivation in the closer and middle region. As farming in the closer region is challenging due to high intensity of groundwater pollution, non-farm activity like powerloom, shops are found to be predominant sources of occupation.

Figure – 3. Distribution of income from different sources among the sample farms (Rs./acre/year)



	On farm income	Off farm income	Total farm income	Non-farm income	Total gross income
Closer region	99433.15	17775	117208.15	505750	622958.15
Middle region	123590.4	45225.34	168815.74	459200	628015.74
Distant region	140678.33	47250	187928.33	212575	400503.33

From the Figure – 3, it is depicted that the middle region has high gross income compared to other two regions. This is because of the reason that the region has good income in farming and also in non-farm sector. However, distant region has high farm income indicating the suitability of agriculture and allied activities. In the closer region non-farm income contributes to 81.19 per cent to the total gross income whereas the sum of on-farm and off-farm is only 18.81 per cent to the total gross income. In the distant region non-farm income is very low compared to other two regions and it is about 53.08 per cent to the total and farm income is about 46.92 per cent to the total gross income. This showed that people in the distant region are dependent upon agriculture than the other two regions and also it is possible because of suitability of water for irrigation.

Table –2. Returns over cost (₹/acre/year)

S.No	**Particulars**	**<1km (Closer region)**	**1-3km (Middle region)**	**>3km (Distant region)**
1	Total Costs	78052.60	84603.80	89986.78
2	Gross income	99433.15	123590.40	140678.33
3	Net income	21380.55	38986.60	50691.56
4	Farm Business income	40797.28	63208.47	77742.20
5	Farm investment income	33454.95	51665.57	63858.08
6	Family Labour Income	28722.88	50529.50	64575.68
7	Benefit Cost Ratio	1.27	1.46	1.56

The measures of returns over different costs namely, farm business income, farm investment income and family labour income were comparatively lower in closer region than middle region and distant region. Thus, it is evident that in closer region, the efficiency of production was low, which may be due to the less yield obtained due to poor quality of water. It could also be observed from the results that the benefit cost ratio was higher in distant region (1.56) as compared to middle region (1.46) and closer region (1.27). This showed that on spending ₹.1 will give in return of ₹.1.27 in the closer region, ₹. 1.46 in the middle region and ₹. 1.56 in the distant region.

Table –3. Estimates of Resource Use Efficiency in Coconut Cultivation

Particulars	Coefficients		
	<1km (Closer region)	**1-3km (Middle region)**	**>3km (Distant region)**
Intercept	1.6613 (1.3892)	1.3315 (1.3053)	6.9817 (0.7033)
ln Manures (X_1)	0.3074 ** (0.1321)	0.1526 * (0.1686)	0.0479 (0.0633)
ln Fertilizers (X_2)	0.3797 * (0.2678)	0.2516 (0.2020)	0.1236 ** (0.0612)
ln Irrigation water (X_3)	-0.0573 (0.0591)	0.0639 * (0.0536)	0.1093 ** (0.0475)
ln Plant Protection Chemicals (X_4)	0.4396 *** (0.1418)	0.4136 *** (0.1274)	0.1665 *** (0.0483)
ln Labour (X_5)	0.0948 ** (0.0555)	0.3025 ** (0.1450)	0.1149 ** (0.0512)
Sum of elasticities	1.1642	1.1842	0.5622
N	40	40	40
R^2	0.8317	0.8730	0.7450
Adjusted R^2	0.8070	0.8543	0.7075

The results of resource use efficiency could be traced from the Table-3. The value of R^2 was 0.83, 0.87 and 0.74 in the closer, middle and distant region respectively. This indicates that 83 percent of variation in the closer region, 87 percent of variation in the middle region and 74 per cent of the variation in the distant region on the dependent variable (gross income) was due to the explanatory variables viz., manures, fertilizers, irrigation, plant protection chemicals and labour charges. The sum of elasticity of regression coefficients was worked out and the value was found to be 1.16, 1.18 and 0.56 in the closer, middle and distant region respectively. This implied that increasing return to scale is operating in the closer and middle region. It can also be stated that 1 per cent increase in all the inputs for coconut cultivation in the closer region and middle region from the geometric mean level would increase the gross income by 1.16 per cent and 1.18 per cent respectively. In other words, there exists a scope for increasing profit by increasing inputs. However, in the distant region 1 per cent increase in all the inputs for coconut cultivation in the distant region from the geometric mean level would decrease the gross income by 0.56 per cent. It can also be stated that profits can be increased by reducing the inputs level.

Among the explanatory variables except irrigation all the other variables were found to be positively influencing gross income in the closer region. This negative effect in gross income might be due to existence of polluted water in the closer region. One per cent increase in the value of plant protection chemicals, fertilizers, manures and labour from the mean level, *ceteris paribus*, would increase the gross income by 0.43 per cent, 0.37 per cent, 0.30 per cent and 0.09 per cent respectively. Similarly, on increasing the value of plant protection chemicals, labour, fertilizers, manures and irrigation by 1 per cent from the mean level, *ceteris paribus*, would increase the value of gross returns by 0.41 per cent, 0.30 per cent, 0.25 per cent, 0.15 per cent and 0.06 per cent respectively in the middle region. All the explanatory variables were found to be positively influencing gross returns in the middle and distant region. One percent increase in the value of plant protection chemicals, fertilizers, labour, irrigation and manures from the mean level, *ceteris paribus*, would increase the value of gross returns by 0.16 per cent, 0.12 per cent, 0.11 per cent, 0.10 per cent and 0.04 per cent respectively. The value of intercept is high in distant region (6.9817) compared to closer and middle region, indicating that very less land degradation due to less groundwater pollution in the distant region.

Table – 4. Decomposition analysis between severely affected and unaffected areas

S.No	Particulars	Percent contribution	Monetary terms (in ₹)
1.	Difference in gross returns	100.00	41245.19
2.	Difference in gross return due to quality of irrigation water	38.73	15974.26
3.	Difference in gross return due to inputs	-2.40	-988.35
4.	Manures	-0.45	-184.45
5.	Fertilizers	-0.48	-197.26
6.	Irrigation water	-0.05	-21.28
7.	Plant protection chemicals	-0.87	-357.63
8.	Labour	-0.55	-227.73
9.	Difference in gross returns due to others	63.67	26260.81

The total difference in gross return per acre of coconut crop between severely affected and unaffected farm was found to be ₹.41245.19 (Table - 4). In the total difference, quality of irrigation water alone accounted for 38.73 per cent (i.e. ₹. 15974.26). The variations due to all the inputs put together negatively contributed to the differences in gross return and therefore the other factors not included in the model accounted for 63.67 per cent and in monetary terms it was ₹.26260.81. The decomposition analysis clearly indicated that quality of irrigation water significantly contributed for reduced gross income. It should be noted that there is existed scope to reduce the difference in gross return between the severely affected farms (closer region) and unaffected farms (distant region) by improving the quality of water.

Table – 5. Decomposition analysis between moderately affected and unaffected areas

S.No	Particulars	Percent contribution	Monetary terms (in ₹)
1.	Difference in gross returns	100.00	17087.93

2.	Difference in gross return due to quality of irrigation water	53.52	9145.52
3.	Difference in gross return due to inputs	-2.92	-498.57
4.	Manures	-1.19	-203.22
5.	Fertilizers	-0.11	-18.69
6.	Irrigation water	-0.11	-18.37
7.	Plant protection chemicals	-0.96	-164.62
8.	Labour	-0.55	-93.67
9.	Difference in gross returns due to others	49.39	8440.99

The total difference in gross return per acre of coconut crop between moderately affected farm and unaffected farm was found to be ₹.17087.93 (Table -5). In the total difference, quality of irrigation water alone accounted for 53.52 per cent (i.e. ₹. 9145.52). The variations due to the all inputs put together negatively contributed to the differences in gross return and therefore the other factors not included in the model accounted for 49.39 per cent and in monetary terms it was ₹.8440.99. The decomposition analysis clearly indicated that quality of irrigation water significantly contributed for reduced gross income. It should be noted that there exists a scope to reduce the difference in gross return between moderately affected (middle region) and unaffected farms (distant region) by improving the quality of water.

Table –6. Estimates of hedonic function analysis

Variables	**Coefficient**	**Standard error**	**t-statistic**
Farm income (in ₹./ac)	13.18 *	6.23	2.12
Scale of pollution intensity	-334937.75	388676.52	-0.86
Distance between land and polluted source(river) (in m)	1822.05 **	118.17	15.42

Distance between land and main road (in m)	-5420.60 **	482.90	-11.23
Constant	1476852.12	86909.78	16.99
N	120		
R^2	0.9648		
Adjusted R^2	0.9636		

The results of hedonic model (Table - 6) indicated that 96.4 per cent variation in the value of agricultural land was explained by explanatory variables viz., Farm income (X_1), scale of pollution intensity (X_2), distance between farm and polluted source (river) (X_3) and distance between farm and main road (X_4). Further the coefficients of X_1 and X_3 were positive indicating they were positively related with value of agricultural land. Similarly, the coefficients of X_2 and X_4 were negative indicating they were negatively related with value of agricultural land.

It could be inferred that one rupee increase in farm income per acre will increase the agricultural land value by ₹13.18 per acre keeping other variables constant and one-meter increase in the distance between farm and the polluted river will increase the agricultural land value by ₹.1822.05 per acre, *ceteris paribus*. Similarly, one-meter increase in the distance between farm and main road will decrease the agricultural land value by ₹. 5420.60 per acre, *ceteris paribus* and if the scale of pollution intensity increases i.e. shifts from unaffected to moderately affected or from moderately affected to severely affected will decrease the agricultural land value by ₹. 334937.75 per acre, keeping the other variables constant. Thus mean the importance of polluted input i.e. irrigation water here causes negative externality to the value of agricultural land.

Conclusion

The study attempts to find the status of groundwater pollution in the Noyyal river region of Tiruppur district. It revealed that the intensity and severity of groundwater pollution is very high closer to the river and gets reduced on moving away from the river. The effect of the same can be seen as reflection from the agricultural income and also in the value of agricultural land, wherein groundwater is used for irrigation. Decomposition analysis and hedonic pricing technique also proves the same. Hence, the study recommends the following

- Zero Liquid Discharge ensures stoppage of industrial effluents into the river and hence, river pollution is stopped. Similarly, an appropriate step is needed for reducing groundwater pollution.
- It is important to avail clean and hygienic water inorder to satisfy our sustainable development goal 6, ensuring the availability and sustainable management of water and sanitation to all. So, there exists a need for framing a suitable policy to reduce groundwater pollution. Tamil Nadu Pollution Control Board can take a necessary step to reduce the groundwater pollution.
- Public Works Department (PWD) may start desalinating all the ponds, tanks, canals and lakes in the Noyyal region and allowing all these structures to harvest rainwater and allow only for groundwater recharge purposes. This will help in reducing the pollution level.
- Farms surrounding the Noyyal river region can allot a small area of land for farm pond construction to store good quality of water during rains in those ponds and allowing for percolation. Hence, percolation of good quality water allows improvement in the quality of groundwater.
- Decline in value of agricultural land in the affected areas was due to the deterioration of water and land quality. Hence, the Government can play a decisive role in

augmenting the land compensation to the farmers in taking up the appropriate agronomic practices and ameliorative measures.

- Field trials may be conducted in order to identify suitable varieties of crops to withstand the use of polluted groundwater for irrigation.

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