Technical and Sociological Investigation of Impacts in Using Lignite Mine Drainage for Irrigation – A Case Study

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Abstract. Irrigated farming depends on an ample supply of water compatible quality. Presently, a lot of irrigation projects have to depend on inferior quality and not so enviable sources of water supply. In order to prevent troubles during usage of such water supplies of poor quality, there must be meticulous preparation to ensure that the water available with such quality characteristics is put to best use. The effect of water quality upon soil and crops must be better understood in choosing fitting options to manage with impending water quality associated troubles that might decrease soil and crop productivity under existing circumstances of water use. Two tanks (small sized reservoirs) namely, Walajah Tank and Perumal Tank in Cuddalore District, used for irrigation, receive mine drainage water pumped out continuously from the open cast lignite mines of the NLC India Limited, Neyveli, Tamilnadu State. This water has been used by the farmers in the irrigated commands of both Walajah Tank and Perumal Tank for more than three decades. Recently, the beneficiaries had raised fears on the quality of mine drainage waters they had been using for raising crops in the commands of both the tanks. They opined that the coal dust laden mine water used for irrigation had affected the crop yields. This incited us to take up a study to (i) assess the status of quality of surface waters released from the two tanks for irrigation in the respective command areas and (ii) assess the likely impacts of quality of water on soil and on growth and productivity of crops cultivated in the command areas. Further to the technical evaluation of the impacts, a structured questionnaire survey was also conducted among the farmers and the common public in the study area. The findings of the survey confirmed with the outcome of the technical assessment in that the mine drainage had a poor impact in the cultivable command area of Walajah tank system while such impacts were less significant in most parts of the command area of Perumal tank system.
Key words: *Lignite mine drainage, irrigation, command area, impact assessment*

1. Introduction

Fast urbanization and industrial growth during the previous few decades have aggravated several severe apprehensions for the environment [1]. In the previous few decades, due to fast growth in industrial sector and increase in population, a tremendous stress has been imposed on the fresh water requirements [2, 3]. Water quality plays a significant part in advancing farming production and health standards of human beings. Quality of water is much dependent on the preferred utilization of water as diverse water uses warrant special standards of water quality requirements [4, 5].

The quality and quantity of surface and ground water resources in several parts of India get intimidated by mining activities [6, 7, 8, 9]. The mine water quality depends on a string of geological, hydrological and mining conditions, which differ considerably from one mine to another [10, 11]. There is a great variation in the concentration of contaminants present in the water discharged from a mine and in certain cases the quality characteristics of mine water may be such that it satisfies the drinking water standards [12]. However, on many occasions, the water discharged from a mine is not usable as such and it may contain beyond maximum permissible concentrations of heavy metals, toxic anions, and organic and biological contaminants [7].

The main proportion of our coal and lignite wealth goes into the production of power and has a massive impact on quantity and quality of surface and ground water resources. Water is used in coal mines for numerous purposes such as washing, spraying, and for preparation of coal. This may result in a disparity with water users in other sectors and requirements of environment. Mining activities result in dewatering of nearby groundwater aquifers, thereby reducing the groundwater table in the surrounding areas. Due to the reduction in water table, agricultural activities, in particular, and other activities that depend upon groundwater get badly affected. Water pumped out from mines, spent water discharged from coal handling plants, water discharged from dust extraction and dust suppression systems, water washed off from overburden dumps, workshops and effluents from domestic systems and washery are the major sources of water pollution due to mining activities. Further, run off resulting from discarded waste dumps and pits turns out acidic causing soil erosion and contamination of surface and sub-surface water systems. Several examples of such invasive impacts are seen in coalfields of Jharkhand, Orissa, West Bengal, Maharashtra, Uttar Pradesh, Madhya Pradesh, Maharashtra and Andhra Pradesh. Luckily many of these are not associated with pyrite and acid mine drainage is not a stern problem. However, a few mines have acid mine drainage problems and a significant example being the coal mines in Meghalaya.

Lignite is primarily utilized for power production in pit head power plants. The proportion of lignite actually used for power production has ranged from 80% to 86% since 2001-02 (during this period, more than 98% of lignite used in Tamil Nadu State was for power production). Mining of lignite in Neyveli is an essence of how mining impacts water resources. Here, mining for lignite situated above artesian aquifers has actually led to destruction of the aquifers above and beneath the lignite and has also incited mining of water in an exceptional scale. Numerous other lignite deposits in India, mostly in coastal Kutch also have artesian conditions and the constant expansion and deepening of lignite mines will ultimately lead to an immense devastation of the storage potentials, loss utilizable groundwater and destruction of the recharge systems.

At present, NLC (India) Limited (previously known as "Neyveli Lignite Corporation Limited) is India's biggest lignite mining organization, and an apex power production entity. Per year, about 24 million tons of high-grade lignite is produced from the three open cast mines operated by the company in Neyveli. Mine I (Northern in the image), which is the first mine of the NLC (India) Limited, extends over an area of about 17 square kilometers and has a reserve of nearly 300 million tons. Mine II which was first struck in early 1984 and got extended in the early 1990s, had a reserve of nearly 400 million tons. The total lignite reserves in the Neyveli mine field are valued at larger than two billion tons. As is evident, a vast area has been opened up totally transforming the surface water flow regimes. The area between the Gadillam and Vellar Rivers has fully altered. Thus, the first and the primary blow of the large scale opencast lignite mine is the devastation of the surface topography and thereby loosing the potential for surface storages and recharge. These changes are irreversible and the swift expansion envisions additional irreparable changes in the surface flow and recharge regimes. The impact of lignite mining in Neyveli on the water regime is particularly severe because of the unique hydrogeological conditions of the region. In the unconfined and semi-confined aquifers lying above the lignite deposit, groundwater is present. In the layers below the lignite deposit, groundwater is present in artesian conditions. This means that in order to reach the lignite, the aquifers be totally destroyed as these layers are the `over burden' for the miner. Thus, second irreversible impact is that the shallow aquifers that would be replenished stop to survive and that renewable storage capacity of the ground water is lost. Presently, about 180000 to 205000 m^3/day of water is pumped out from NLC and another 160000-180000 m^3/day of water flows from agricultural wells, which account for a total withdrawal from aquifer of about 140 M m^3/yr. The paradox of lignite based power development, predominantly for the local people, is the community blessed not only to have surface sources but also groundwater sources which would be available at the source without use of external energy and simply have to dig pits to receive their water as the supply is at such low-pressures.

The mine waters of NLC India limited are continuously drained through Upper Paravanar to the surface water body, namely Walajah Tank. As the water drained out is in huge quantities, the surplus water gets continuously drained to the downstream surface water body, namely Perumal tank through middle Paravanar. The water in these two tanks is utilized mainly for irrigation in the respective command areas of the tanks. Even during failures of monsoon, the farmers in the irrigated commands of these two tank systems could benefit from using the mine drainage by raising two crops successfully each year. However, the farmers, particularly in the command area of the Walajah tank system, raised fears that the yields of crops have decreased in the recent years. This necessitated a pilot study with the following objectives:

i. to assess the status of quality of surface waters released from the Walajah Tank System as well as the Perumal Tank System for irrigation in the respective commands, and
ii. to assessg the status of soil properties in the command areas of the Walajah Tank System and Perumal Tank System and their impact on growth and yield of crops.

2. Study area

The Walajah Tank irrigation system and Perumal Tank irrigation system form part of the Sethiathope Project. These are situated on the left bank of the River Vellar, in the Cuddalore District, bordered on the east by coastal sand dunes. The climate of the area is monsoon type with a mean yearly rainfall of 1284 mm with nearly two-thirds of this yearly rainfall occurring mostly during the North-East monsoon period of October-December. As the study area is situated in the flood plain of the River Vellar, it suffers chronically from a shortage of water before September and from frequent floods during November-December either by the Vellar or by the Paravanar River. Paravanar River is a major drain crossing the area from West to North-East. Thanks to the continuous supply of water from the Neyveli mine drainage, the commands of both Walajah and Perumal Tank Systems could be irrigated throughout the year. Figure 1 shows the location map of study area.

Walajah Tank has a very limited storage capacity but a relatively huge command area. Due to human encroachment, the original storage capacity of 2.57 million cubic metres has reduced to 1.66 million cubic metres. Further, as a major portion of the tank has been infested by weed growth, the capacity of the tank has been further reduced. Under these conditions, Walajah Tank does not act as a tank and does not fulfill the function for which it is constructed. The tank receives water (i) through runoff generated from its own catchment during the rainy season, (ii) through inflow from Neyveli mines throughout the year and (iii) through surplus waters released from Veeranam tank through the Vellar Rajan Canal. Walajah tank has a total command area of 11,292 acres which is served by 12 channels benefiting a total of 22 villages.

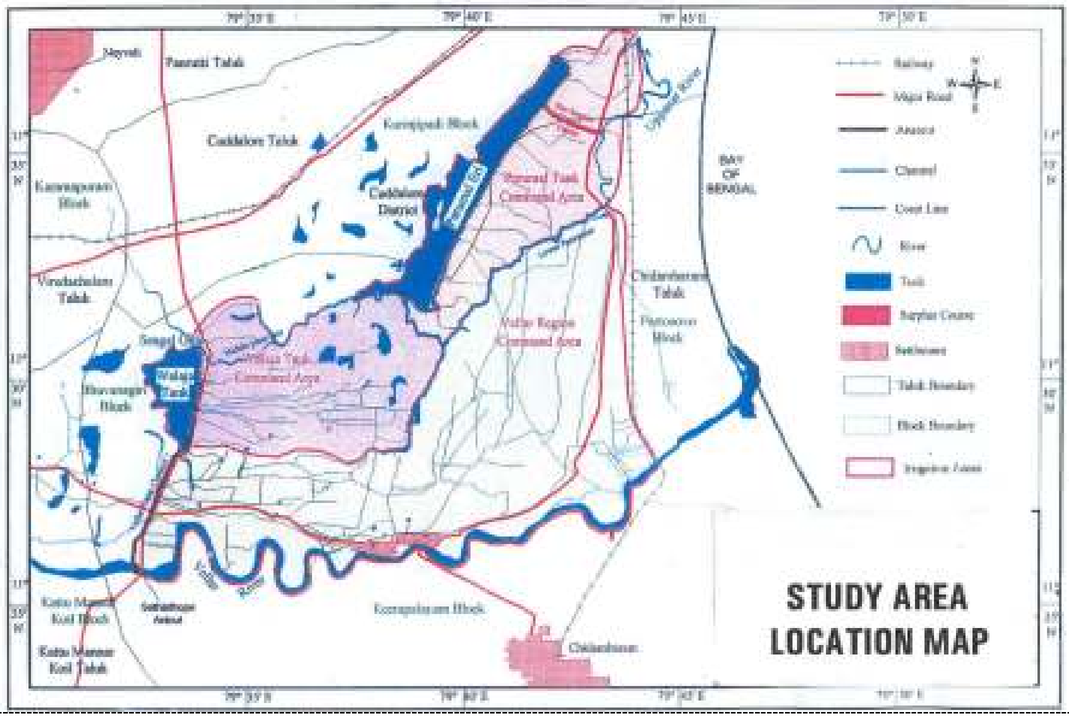

Figure 1. Location map of study area.

The Perumal tank has a storage capacity much larger than that of the Walajah tank. The combined catchment of Perumal tank is 552.9 sq. km and it has an original capacity of 16.25 million cubic metres. During the years, the tank has silted up in part and its storage capacity has decreased to 13.5 million cubic metres. The tank feeds water for irrigating a command area of 6,503 acres through 11 off-taking channels. A total of 20 villages are benefited by the tank. Two weirs located on the southern flank of the tank, near the point where the Paravanar River joins the tank, protect the tank against flooding. These two weirs discharge the surplus waters into the Lower Paravanar River. The tank receives runoff from its catchment and water surpluses from Walajah Tank through the Middle Paravanar. Water is released almost throughout the year through the surplus arrangement from Walajah tank to Perumal tank due to the continuous inflow to Walajah Tank from Neyveli mines.
Soils in the Sethiathope Command consists predominantly of fine grade alluvial soils, clays and clay loams traversed by zones of coarser soils of sandy loams.

Paddy is the principal crop grown in the commands of both tank systems. As the ryots of both tank systems are blessed with continuous availability of water in the form of mine drainage from Neyveli, they raise two crops in a year. The first crop of paddy is usually a short term variety grown in June/July to September/October. The second crop in the commands of Walajah Tank is a medium variety paddy crop grown during September/October to January/February, while the second crop in the commands of Perumal Tank is also a medium variety of paddy but grown during December-January to March/April. As the water availability is scarce during the South-West monsoon period, the first crop covers only about 33 percent of the command area. The second crop, which is grown during the North-East monsoon period, covers about 90% of the command area.

3. Water quality assessment of surface waters of Walajah tank and Perumal tank systems

A problem of salinity subsists, when a loss in yield is caused due to excess concentrations of salt built up in the crop root zone. The problem of salinity in irrigated areas occurs from a saline, high water table or from salts present in the water applied for irrigation. When the accumulation of salts in the crop root zone occurs to such a level that the crop is no longer able to extract water from the salty soil solution, the crops are in water stressed condition for a longer time period thereby effecting yield reductions in the crop. The growth rate of crop is greatly reduced due to marked reduction in uptake of water. The salts which cause the problem of salinity are soluble in water and are transported at ease by water. During irrigation, when more quantity of irrigation water gets infiltrated into the soil than that being used by the crop, it would be helpful in removing a portion of salts accumulated in the crop root zone during previous irrigations by leaching them below the root zone. Leaching is the key factor in mitigating a water quality-related salinity problem. The quantum of leaching required depends upon the quality of irrigation water and tolerance of the crop grown to salinity.

A problem of infiltration in relation to quality of water occurs when the rate of infiltration of the water applied for irrigation or rainfall is significantly reduced and water remained on the soil surface for a pretty longer duration or infiltrated very slowly thereby hampering the supply of adequate water to the crop for obtaining acceptable yields. Soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also significantly affect the water intake rate.
The two main water quality parameters that affect the normal infiltration rate are the salinity of water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content. Water with high salinity will augment infiltration. Water with low salinity or water with a high sodium to calcium ratio will reduce infiltration. Both factors may function simultaneously.
The assessment of quality of waters of both Walajah and Perumal tank systems used for irrigation is done referring to the "Guidelines for interpretation of water quality for irrigation" given by FAO Irrigation and Drainage Paper 29 Rev. 1 [13]. The classification of irrigation water based on Electrical Conductivity (EC) and Sodium Absorption Ratio (SAR) proposed by USSL [14] has been used in the present study.

Rice is categorized as a moderately sensitive crop with regard to salt tolerance. Table 1 shows the tolerance and yield potential of rice crop as influenced Electrical Conductivity (EC) of water used for irrigation and that of soil in which crop is grown.

Table 1. Crop tolerance and Yield Potential of rice as influenced by Irrigation Water Salinity (ECw) and Soil Salinity (ECe)

Field Crop	**Yield Potential (in percent)**									
	100		90		75		50		0	
	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
Rice	2.0	3.0	2.6	3.8	3.4	5.1	4.8	7.2	7.6	11.0

The EC of water samples drawn from various reaches of different channels of Walajah Tank System showed a variation from a low of 1.016 dS/m to a high of 2.200 dS/m. For majority of the samples of water, the Electrical Conductivity was found to be in the narrow range of 1.500 to 1.800 dS/m.

The EC of water samples drawn from different reaches of various channels taking off from Perumal Tank System ranged between a low of 0.526 dS/m to a high of 1.531 dS/m The water samples drawn from six Channels were found to be within 0.750 dS/m. The EC of water in Kundiamallur and Manvaikkal channels lie in a close range of 1.466 dS/m to 1.531 dS/m. in the other channels mamely, Kallaiyankuppam Channel, sirupalaiyur Channel and Theerthanagiri Channel, the EC values lie in the range 0.740 dS/m to 1.527 dS/m. Comparatively speaking, the EC values of waters of Perumal Tank System were less than the waters of Walajah Tank System. Both tanks almost continuously receive the Neyveli Mine Drainage with Walajah Tank located on the upstream of Perumal Tank. As the storage capacity and catchment area of Perumal tank are much higher (about 6 times and 3 times respectively) than that of the Walajah Tank, whenever rainfall occurs in the catchment of Perumal tank it augments the local inflow to the tank in addition to the Neyveli drainage water. This rain water dilutes the concentration of total dissolved salts present in Neyveli Mine Drainage resulting in lesser EC of irrigation waters of Perumal Tank. Because of lesser storage capacity and lesser catchment area, the inflow from the local catchment of Walajah Tank during periods of rainfall does not add to the storage much and has less diluting effect on the waters of Neyveli Mine Drainage. Therefore, the EC of irrigation waters of Walajah Tank System are much higher.

The SAR values of water samples drawn from irrigation channels of Walajah Tank system fell in the range between 1.650 and 3.515. But, for most of the water samples, the SAR lied in a close range of 2.028 and 2.942.

For irrigation waters of Perumal Tank system, the SAR values were in the range 1.696 to 3.249. The water samples drawn from different reaches of six out of eleven channels had SAR values in the range of 3.249 to 2.307 (Theerthanagiri Channel) while in the other 5 channels, the SAR values were found to be relatively lesser in the range 1.696 to 2.576. Comparatively speaking, in general, the SAR values of irrigation waters of Perumal Tank System were found to be less than those of Walajah Tank System.

On the average, the SAR values of most of the water samples tested indicate SAR values less than 3.0 for both Walajah and Perumal Tank irrigation systems. Therefore, as per the rules for interpretation of water quality for irrigation referred previously, for SAR between 0 and 3 and EC of water greater than 0.7 dS/m, there is no limitation on utilization of water for irrigation.

As per the USSL Salinity diagram for irrigation water, in general, the irrigation water of Walajah Tank may be categorized as Class C3-S1 (that is, low sodium hazard and medium-high salinity hazard). The quality of water of Walajah Tank for irrigation is under moderate category. In case of Perumal Tank System, the irrigation waters of six channels fell under the Class C2-S1 (that is, low sodium hazard and moderate salinity hazard). The quality of waters of these channels for irrigation is under good category. The quality of irrigation waters of the other five channels of Perumal Tank fell under the category C3-S1 (moderate quality).

Hence, going by the above standards and considering also the crops grown in the commands of both Walajah and Perumal Tank irrigation systems, there is no problem of salinity and no problem of infiltration caused by SAR.

But, the farmers of Walajah Tank System, in particular, say there has been reduction in the yields of rice crops grown in the command area in the recent years. *Why?*

It was observed that the turbidity of irrigation waters flowing in many of the channels of Walajah Tank System was high. The high turbidity of waters could be attributed mainly to the colloidal suspended particles, mainly the coal dust present in the Neyveli mine drainage. This revealed that the Walajah Tank was not functioning as an effective storage unit and simply acted as a receiving unit before passing on the mine drainage from it directly to the off-taking irrigation channels. No effectual settling of drainage water took place in the tank. This was essentially due to the insufficient storage capacity of the Walajah Tank to permit successful settling of the suspended particles in waters received by it, particularly the mine drainage which is received continuously by the tank all throughout the year. Further, even the original storage capacity of the tank was not available due to sedimentation, weed growth and encroachments. Simply, the mine waters drained to Walajah Tank flowed in the form of a channel course nearer to the eastern bund of the tank before getting discharged through the various sluices. Altogether, there is no storage at all in the Walajah Tank. Hence, Walajah Tank does not serve the primary function expected of a tank, that is, storage.

It was found that the turbidity of waters released through the channels of Perumal Tank system for irrigation was very less. The analysis of water samples drawn from different reaches of different irrigation channels revealed that the suspended solids were very less and could be practically ignored. That is, the higher available storage capacity of Perumal Tank was successful in trapping the suspended particles present in water.

To identify the possible effects of these colloidal particles (including the micro particles due to coal wash present in mine drainage) on irrigated soils, it necessitated the evaluation of fundamental physical properties of field soil samples, namely, bulk density, particle size distribution and permeability.

4. Physical analysis of soil samples

Table 2 shows the optimum bulk density for maximum plant available water and field range bulk densities for a range of textures [15].

Comparing the data from Archer and Smith [15] in Table 2, it is obvious that for sandy soils with less plant available water capacity, an increase in bulk density can be helpful. However, on heavier soils, the optimum bulk density seems to be lesser than the bulk density of fields under cultivation and hence the problem is to keep the bulk density as low as feasible. Thus, a rise in bulk density in fine grained soils will lead to a fall in the amount of macro pores thereby decreasing plant available water at low suctions. At high suctions, a rise in bulk density boosts soil water retention (not plant available) and the net effect is a decrease in plant available water. Although a rise in bulk density might enhance water withholding properties of certain soils, high densities are objectionable in all soils as resistance to root penetration is increased leading to hindering growth and distribution and hence decreasing water use efficiency.

Table 2. Optimum Bulk Density[1] for maximum Plant Available Water and Field Range Bulk Densities for a Range of Textures

Soil	Optimum density (g/cm^3)	Field Density (under cultivation)	
		Range (g/cm^3)	Mean (g/cm^3)
Loamy sand	1.75	1.23 - 1.59	1.52
Sandy loam	1.50	1.05 - 1.72	1.34
Silt loam	1.40	No data	No data
Clay loam	1.20	0.94 - 1.57	1.30

[1]*Optimum Bulk Density is the bulk density where plant available water is maximum*

It was observed that the bulk densities of almost all soil samples collected from the Walajah Tank command were high and more than the recommended permissible range for effective uptake of nutrients by the crops grown. In Perumal Tank command area, the bulk densities of soil samples were relatively lesser.

Sieve analysis was also performed on undisturbed soil samples collected from the command in the head reaches of certain channels of Walajah Tank System, to determine the particle size distribution. it is found that the content of clay in field soil samples drawn from cultivated lands of Walajah Tank Command is high. Considering the particle size distribution and the recommended range of field density, it is most likely that the higher bulk densities of soils will have a negative impact on growth of crops grown.

The permeability of soil gets reduced with increase in percentage of clay-sized particles. Permeability of soil is one of the key factors in making the nutrients available to the root zone of the crops grown. Depending upon the soil type and groundwater levels, the inundated rice fields will have a continuous water percolation to the deeper layers. Agronomists opine that the percolation process is favorable for the plant growth, as the water movement will keep oxygen content within the soil at a reasonable soil. Normal percolation rates are 1-3 mm/day on soils with high clay content. It was observed that the permeability of all soil samples were very less. This might have hampered the growth of the crops grown in the study area.

5. Socio economic impact assessment

A structured interview schedule was prepared and translated into the local vernacular (Tamil) language to obtain information from the villagers of the command. The respondents were asked to provide information on the suitability of NLC mine drainage for irrigation, impact on soils, impact on crop yield, employment potential and health. All the 22 villages of the Walajah command and 21 villages of Perumal command were included in the study. A total of 430 households were chosen using a stratified random sampling technique in both the commands.

In Walajah tank command area, over 40 (42) percent of the respondents expressed that the NLC mine drainage was suitable for raising crops while about 60(58) percent of the respondents felt that it was not suitable for crops. For Perumal tank command, about two-thirds of the respondents viewed positively the suitability of NLC mine water for irrigation and only one-third (35%) of the respondents felt negatively.

It was also aimed to find out the respondents' views regarding the impact of NLC mine waters on the yields of crops. Under the Walajah tank command, a well over 80 (80 & 85) percent of both large and small farmers expressed their concern with regard to reduction in crop yields due to NLC mine waters. On enquiry they expressed that in general they lose 5 to10 bags of paddy per acre per season. On the other hand in Perumal tank command nearly three quarters (78% & 77%) of respondents each belonging to large and small farmers category highlighted that there was no significant change in the yield due to irrigation waters. Only about 20% of the respondents in each category revealed that there was decrease in yield.

In the Walajah Tank Command, majority of the respondents (62%) viewed that the quality of the NLC mine drainage water had affected the soil quality whereas in the Perumal Tank system only 40 percent of the respondents had opined that the water affected the soil fertility. However, a majority of the respondents (60%) belonging to Perumal command reveal that the water had not damaged the soil quality and they got yields normally.

The results of the impact assessment of NLC mine drainage on the commands of Walajah tank and Perumal tank, on the basis of the field study, reveal that in general the mine drainage water is suitable for irrigation. Though some respondents in the Walajah command revealed that there was some loss in yield due to the quality of irrigation waters, the respondents of Perumal tank system revealed that there was no such reduction in the yield due to irrigation waters. Also, the respondents of both the commands, Walajah tank command in particular, revealed that irrigation water had affected the soil quality and yield to some extent, the extent of damage caused was not alarming. The respondents suggest that in order to improve the impact of nlc mine waters, treating water before it was released for irrigation from the Walajah tank and strengthening the agricultural extension services of the state agricultural department in order to suggest appropriate farming strategies that would go a long way in sustaining their future. Since the NLC mine drainage happens to be their main source of irrigation, which provides them employment throughout the year, the respondents expressed their concern for proper and wise use of irrigation waters. They expressed that NLC mine water is the only lifeline for the people of their region.

6. Conclusions and Recommendations

- There is no problem of salinity and no problem of infiltration caused by SAR in the commands of both Walajah and Perumal Tank irrigation systems.
- The turbidity of irrigation waters flowing in many of the channels of Walajah Tank System was high mainly due to the colloidal suspended particles, mainly the coal dust from the Neyveli Mine Drainage. This is basically due to the inadequate storage capacity of the Walajah Tank to allow effective settling of the suspended particles in waters received by it. The turbidity of waters released through the channels of Perumal Tank system for irrigation was very less as the available storage capacity of Perumal Tank was adequate in effective trapping of the suspended particles present in water.
- The higher bulk density and reduced permeability of soil samples drawn from various irrigated fields of Walajah Tank indicated that there was a likely problem of infiltration. The physical nature of the soils was such that it was not permeable to the extent needed by the crops grown in the command area. As the permeability was less, it had reduced the uptake of water by the root tips and caused a water stress situation to the crops thereby affecting the yield of the crops.
- Removing the weeds, removing the encroachments and desilting of Walajah tank would help in resotaration of the original capacity of the Walajah tank. Further, the storage capacity of the tank can be enhanced by deepening the lowest bed level of the tank. These two measures combined together will make Walajah tank to perform efficiently in settling of colloidal coal dust particles in mine water received by it.
- For decreasing the bulk density and increasing the permeability of soil in agricultural lands in order to create a favourable physical environment for crop growth, more of organic like farmyard manure, crop residuals, press mud, organic waste, and other farm waste and green manures can be added adequately.
- The results of socio-economic impact study reveals that to some extent the water has damaged the quality of soil especially in Walajah Tank command and affected the crop yields. The respondents suggest appropriate treatment of water be made before it is released from Walajah Tank for irrigation.
- To summarize, restoring the original storage capacity and further deepening of Walajah Tank for effective settling of sediments in mine water, incorporation of various organic waste and farm waste, inclusion of green manure to improve both physical status and nutrient availability of soil to sustain the soil health and to realize better yield thereby improving the standard of living of the farming community.

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