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Marginal Waters for Agriculture – Characteristics and Suitability Analysis of Treated Paper Mill Effluent

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1. Introduction

With increasing global population, the gap between supply and demand for water is widening and is reaching such alarming levels that in some parts of the world it is posing a threat to human existence. Scientists around the globe are working on new ways of conserving water. On the other hand, disposal of municipal wastewater and industrial effluents are causing major environmental problem and attempts are being made all round the world to recycle and reuse it effectively and efficiently. Utilization of the marginal quality water for agricultural is in fact an appropriate technology. Agricultural scientists throughout the world are looking into the possibility of using saline and marginal quality of water for irrigation (Ayars et al., 1993; Tanji, 1997; Bajwa, 1997;Alazaba,1998;Franco et al.,2000 and Sivanappan,2000), social forestry, development of pasteur land, artificial recharge, aquaculture and wet land development. Wastewater reuse, reclamation and recycling are essential in coming years for the development of sound water and environment management policies. In arid and semi arid regions marginal water utilization is a vital component of their water resources development ensuring alternative water resources, sustainability, reduction of environmental pollution and health protection. Wastewater from different industries, which falls under marginal water quality, can be utilized beneficially for irrigation if proper treatment, monitoring and management measures were taken. The challenges and the benefits of marginal water quality utilization has to be ascertained and appropriate package of practices which are location specific needs to be followed for the real success and long term sustainability.

1.1 Wastewater irrigation - Domestic

Wastewater reuse is as old as civilization. Wastewater reclamation and reuse may produce reliable source of water even in drought years. It provides a unique and viable opportunity to augment traditional water supplies (Asano, 2002). It can help to close the loop between water supply and wastewater disposal. Moreover, nutrients beneficial to plant growth are

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available in the domestic waste. Irrigation water and plant nutrients being limiting factors for agricultural production in the country, exploitation of nutritional/manurial and irrigational sources from wastewater is an appropriate strategy. Many farmers use treated or untreated wastewater for irrigation. In Israel 65% of domestic wastewater is treated and used for irrigation. In fact, the 30% of irrigation is done by the wastewater and the potential is likely to be increased to 80% by 2025.(The arid and semi arid areas of the world can easily augment 15 to 20% of their water supply through reuse of wastewater (Abul, 1989). Water recycling and reuse is expanding rapidly throughout the world. Rough estimates indicate that at least 20 million hectares in 50 countries are irrigated with wastewater (Hussain et al., 2001). There are more than 1000 reuse systems in United States (Arber, 2000). Shelef and Azov (1996), illustrated the current experiences in various countries in Mediterranean region. Videla et al., (1997) has explained the experiences of wastewater treatment in Chilean forest industry. Tsagarakis et al (2001) highlighted the problems and management of wastewater in Greece. Barbagallo et al (2001) opined that the planned exploitation of municipal and industrial wastewater would help to meet the irrigation water demand in Italy. Lazarova et al (2000) highlighted the role of wastewater reuse in the development of new integrated resource management strategy in Europe and Middle East. Thus the necessity of wastewater irrigation has been realized and recognized worldwide resulting in increased expansion of wastewater irrigation programmes throughout the world.

1.2 Wastewater irrigation - Industrial

Though the concept of reusing and recycling for irrigation was an age-old practice, the industrial effluent irrigation is only of recent. It has been adopted with great vigour by most industries because the effluent standards to be met for disposal are higher when compared to land application and the pollution control measures are implemented by effective legislation and by the State Pollution Control Board. Wastewater from different industries, which falls under marginal water quality, can be utilized beneficially for irrigation with proper management. The effluents from agro based industries, which use agriculture products as the raw material, and industries, which involved in processing of agricultural products are not detrimental to the environment since the wastes are organic in nature and biodegradable (Raman et al 1996 and Ramaswamy 1999). Industrial effluent has been widely used for agricultural purposes nowadays. Researchers have tried industrial effluent from paper mill (Rajanan and Oblisami 1979; Pushpavalli 1990 and Srinivasachari 2000), sugar mil (Zalawadia et al 1997 and Kathiresan et al 1998) and distillery unit (Mohan Rao 1998 and Nagappan et al 1998) and favoured effluent irrigation from the respective industries for different crops. Similarly effluent from industries like textile (Singh et al 2001), tannery (Wilson 1998 and Murthy 1999), rice mill (Pathan and Sahu 1999), sago (Muthuswamy and Jeyabalan 2001), aquaculture (Al-Jaloud et al 1993), treated oil refinery (Aziz et al 1994), steel plant (Sharma and Naik 1999), soap and detergent (Somasekhar and Seetharamaiah 1993) and olive mill (Cox et al 1997) were assessed. These research papers in general advocates the cautious use of effluent (i.e) dilution and irrigation for non-consumable crops. Based on the type of the industry, the effluents may be beneficial or harmful to crop plants (Somasekhar et al 1984). It is estimated that as much as 40 - 50% of water can be reused out of water or effluent discharge of paper mill, iron and steel and thermal power plant (Ramana 1991). Sarikaya and Eroglu (1993) grouped the industries depending on the possibility of irrigation reuse of their wastewater as shown in Table 1.

Industry Group	Possibility of irrigational reuse	Some selected examples
I	Irrigational reuse of effluent is permitted	Beer, Vine, Yeast, Starch, Micro food canning
II	May be permitted on certain conditions	Sugar, Slaughter house, Meat processing, Tanning, Pulp and paper, Textile
III	Not suitable as irrigation water	Paint, Polish, Soap, Pharmaceutical, Metal sulphide, cellulose.

Table 1. Industrial Effluent for Irrigation

Whenever an industry discharges its effluents in a hydrological basin, recycling of wastewater for irrigation has to be encouraged. The decision to use effluents for irrigation is dictated by factors like location of the industry, seasonal increase in irrigational practice, where low flow of surface water coincides with the increase in irrigational water, advanced agricultural practices necessitating supplementary irrigations at various stages of plant growth to derive best advantage, drought condition and rising cost of wastewater treatment. In a tropical and developing country like India, where the water for irrigation is in short supply, above considerations lay emphasis on the priority for an industrial wastewater to be disposed of as irrigation water.

Industries today face the question on how to dispose the effluents. The problem is still more acute for industries, which consume large quantity of water, and in turn lets out huge volume of effluent. Paper industry comes under this category. Paper pervades all walks of human activity and thus pulp and paper industry has been responsible for important technical, social and economic impacts in a country. Basic process of papermaking has gone through a few modifications when compared to other industries, yet water could not be replaced though its use has been reduced to a great extent. The industry continues to utilize large quantities of water right from the stage of washing fibrous raw materials to the drying of paper. In the Indian context, around 200-240 m^3 of water is consumed per tonne of paper and to that extent around 180 - 220 m^3 of effluent is generated. Pulp and paper industries in general are among those highly polluting industries in India and Central Pollution Control Board has identified it as one among the 17 polluting industries for monitoring and regulating the pollution from them. Considering the industrial growth vis-à-vis the pollution of water resources, even the advanced countries have never tried to curb the industrial growth in spite of insistence of pollution control measures. In developing countries, particularly those in arid parts of the world, there is a need to develop low cost and low technology methods of acquiring new water supplies for their exploding population while protecting the existing source from pollution. The utilization of industrial effluents for irrigation is an appropriate solution in this context as it involves two main principles – use of soil as a treatment system preventing pollution of the surface water and use of wastewater as continuous or supplementary source of irrigation. In certain cases the dearth of nutrients can also be possibly compensated to a limited extent. Thanks to the effective legislation and implementation of pollution control measures by the State Pollution Control Board. Effluent irrigation programme has been adopted with great vigour by most industries. The present paper throws light on the characteristics of the paper mill effluent water and its suitability for irrigation.

2. Materials and methods

The paper mill located at Pallipalayam in Nammakal district, Tamilnadu was selected for the present study. The effluent treatment plant in paper mill includes primary, secondary and tertiary treatment units. The primary treatment plant includes primary clarifier, vacuum filter and the secondary treatment includes the aerobic lagoon and anaerobic lagoon. The tertiary treatment system consists of masonry baffles, cascades and a bed of blue metal chips. The wastewater collected at various sources is let into the degreasing tank where oil and grease are removed by an oil skimmer or manually. Lime is added in the inlet channel itself to attain a pH of 8.0. The water from the degreasing tank is collected in a collection tank and pumped to first aerator tank where a floating type aerator is arranged. In the collection tank, the pH and temperature of water are stabilized. There are two fixed aerators in second aerator tank. Thus water is exposed to atmospheric air continuously and the BOD of water is much reduced. Nutrients such as urea (30 kg/day) and di ammonium phosphate (20 kg/day) are added in solution continuously at the aerator tank. The over flow water from second aerator tank is let into the clarifier. The sludge formed at the bottom of the clarifier is recirculated till it reaches 3000 rpm. If it exceeds this value, it is sent to the sludge drying beds. The clear overflow from the clarifier (i.e. treated effluent) is pumped to the irrigation fields. The treated effluent water from the pulp mill was pumped into the anaerobic lagoon located 3 km away from the paper unit. After reduction of BOD level, the effluent water is supplied to the farmers through high-density polythene pipes. There were four wastewater streams coming from the industry and let in for irrigation after the treatment and hence four sampling stations (E1, E2, E3 & E4) were identified for periodic sampling. (Fig 1). Quarterly sampling was done for three years. New 1-liter polyethylene bottles were used for sample collection and preservations. The characteristics of the effluent was assessed by the chemical analysis of effluent waters as per the standard procedures (APHA,1995) and the suitability is evaluated for salinity hazard, sodicity hazard, alkalinity and toxicity using parameters such as SAR, Kellys ratio, USSL classification etc and the formulae is given in Table 2.

Parameter	Author	Formula
ElectricalConductivity (dS/m)	USSL (1954)	EC value
Sodium Percent	Eaton (1950)	$\frac{Na * 100}{(Ca+Mg+Na+K)}$
SodiumAdsorption Ratio (SAR)	USSL (1954)	$\frac{Na}{\sqrt{(Ca+Mg)/2)}}$
Kelley's Ratio	Kelley (1940)	$\frac{\mathbf{Na}}{(Ca+Mg)}$
Residual Sodium Carbonate (RSC)	Eaton (1950)	$(CO_3 + HCO_3) - (Ca + Mg)$
Magnesium hazard	Paliwal (1972)	Mg / (Ca + Mg)
Chloride concentration	Ayers and Branson (1975)	Chloride concentration in meq/l

Table 2. Parameters for the suitability of effluents for irrigation

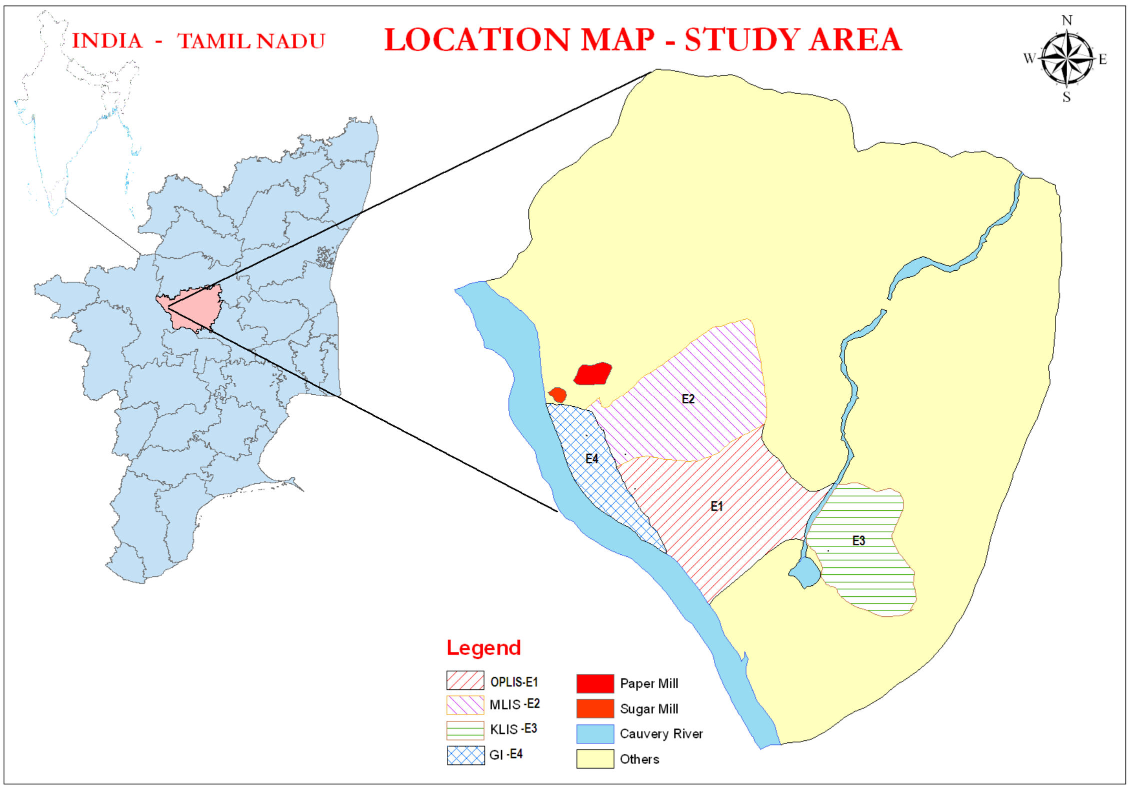

Fig. 1. Location Map

3. Results and discussion

3.1 Effluent characteristics

The average values of the effluent quality collected at different locations are given in the Table 3.

Parameters	E1	E2	E3	E4	Irrigation standards (BIS 1988)
pH	7.99	7.85	7.70	7.91	5.5 - 9.0
EC(dS/m)	1.65	1.51	1.66	1.68	
BOD(mg/l)	48.00	12.00	9.60	36.00	100
DO(mg/l)	0.80	2.90	2.70	0.90	
COD(mg/l)	318	73	81	281	250
Ca(mg/l)	115.11	120.75	107.78	109.56	
Mg(mg/l)	51.33	42.38	49.11	57.22	
Na(mg/l)	147.00	134.75	177.89	144.22	
K(mg/l)	76.11	22.25	20.44	21.78	
HCO_3(mg/l)	295.00	281.50	307.11	277.89	
SO_4(mg/l)	69.44	152.88	115.33	87.89	1000
Cl(mg/l)	306.49	283.63	355.11	353.22	600
Total N(mg/l)	1.90	1.70	2.01	1.80	
Total P(mg/l)	0.09	0.03	0.09	0.01	

Table 3. Characteristics of effluents

The colour of the effluent let out for irrigation for different schemes was of light brown in colour and the effluent had phenolic smell. Srinivachari (2000) reported that the colouring body present in the wastewater was organic in nature and contain wood extractives lignin and degradation products. The unpleasant phenolic odour of the effluent might be due to the presence of hydrogen sulphide and other organic sulphides present in the effluent, which was evident from the higher content of sulphate in the effluent sample (69.44 to 152.88 mg/l). The effluents collected from different sampling locations are alkaline (pH ranged of from 7.70 to 7.99, which confirms that they are alkaline in reaction. This might be due to addition of sodium compounds viz., caustic soda, sodium sulphate and sodium carbonate for the cooking of chopped raw material in the Kraft pulp process. The electrical conductivity (EC) of the effluent ranged from 1.51 to 1.68 dS/m. This high EC could be attributed to the use of various inorganic chemicals at various stages of paper manufacturing.

The BOD values ranged from 9.60 to 48 mg/l which is well within the permissible limit of 100 mg/l (BIS, 1984). Since the organic wastes in spent Kraft pulping liquor are burned and recovered for energy, they do not contribute to the mill effluent BOD and hence the BOD loading in kraft mill effluent is relatively low. The BOD of the effluent at E1 and E4 were 48 mg/l and 36 mg/l respectively, whereas the BOD of the effluent samples at E2 and E3 were well within 30 mg/l and can be drained into the river (BIS, 1984). The effluents from E2 and E3 are allowed to go to anaerobic lagoon and the reduction in BOD could be achieved by the prolonged anaerobic degradation of dissolved organic matter by biological oxidation. The amount of dissolved oxygen was less in E1 (0.8 mg/l) and E4 (0.9 mg/l). The DO in other samples varied between 1.3-2.9 mg/l. The COD was above 250 mg/l in E1 (381 mg/l) and E4 (281 mg/l) whereas the effluent samples from E2 and E3 are well within the permissible limit.

The average values of cations calcium, magnesium, sodium and potassium content in the treated mill effluent collected from different locations ranged from 107.78 to 120.75 mg/l , 42.38 to 57.22 mg/l. 134.75 to 177.89 mg/l and 20.44 – 76.11 mg/l respectively. The average values of anions viz, bicarbonate, sulphate and chloride content of the effluents in the study area ranged from 277.50 to 334.00 mg/l, 69.44 mg/l to 152.88 mg/l from 283.63 mg/l to 355.11 mg/l respectively. The high sulphate content in the paper mill effluent has been reported by Sreenivasalu (1999). This high chloride content may be due to the chemicals used in bleaching. The present study showed that the effluents contain relatively higher concentrations of cations and anions. The perusal of effluent characteristics given in Table 3 shows that the effluents are well within the permissible limits according to Indian standards IS 2490 part – I 1981 (BIS -1988).

It could also be observed from the Table 3 that the concentration of total nitrogen ranges from 1.3 to 2.01 mg/l and total phosphorous ranges from 0.01 to 0.09 mg/l. This indicates that a major inorganic nutrient in the effluent collected from different sampling sites was of low concentration. This might be due to the little usage of nitrogen and phosphorous containing chemicals in papermaking. Javireen (1991) also stated that the concentration of inorganic nitrogen is low and hence biological methods for the nitrogen removal are not required.

3.2 Suitability of effluents for irrigation

The characteristics of the effluent was compared with the tolerance limit for the industrial effluents for irrigation as given by BIS (1988) (Table 4). Various specifications have been proposed from time to time by different workers to assess the suitability of irrigation water. The guidelines for acceptable salinity and minor element levels in effluent water follow those of normal irrigation water (Ayers & Westcot, 1985). For the present study the characteristics of irrigation water that has been recognized to be the most important were salinity, sodicity, alkalinity and toxicity. Thus the suitability of effluent based on various quality criteria is given in Table 4.

Parameters	E1	E2	E3	E4	Permissible limits	
Electrical Conductivity (dS/m)	1.51	1.65	1.66	1.68	< 0.25 0.25 – 7.5 7.5 – 2.25 > 2.25	Low Medium High Very High
Sodium Adsorption Ratio	2.69	2.86	3.56	2.78	< 3 3 – 9 9 – 26 > 26	Low Medium High Very High
Kelley's Ratio	0.62	0.64	0.82	0.62	< 1 1 – 2 > 2	Good Marginal Unsuitable
Sodium`Percentage	36.76	34.92	43.76	36.89	< 60 % 60 – 75% > 75%	Good Permissible Unsuitable
Residual Sodium Carbonate (meq/l)	-4.80	-4.89	-4.38	-5.28	< 1.25 1.25 – 2.5 > 2.5	Good Suitable Unsuitable
Mg Hazard (%)	36.64	42.36	42.89	46.26	< 50 > 50	Good Unsuitable
Chloride concentration (meq/l)	7.91	8.55	9.98	9.85	< 4 4 – 7 7 – 12 12 – 20 > 20	Excellent Good Permissible Doubtful Unsuitable

Table 4. Suitability of effluent based on quality parameters

3.2.1 Salinity hazard

The salinity of the irrigation water was evaluated based on electrical conductivity (EC) measurement, The EC of the effluents collected from the different schemes ranged from 1.51 to 1.68 dS/m (Table 1), Saline water can be used for irrigation with suitable amendments and better management practices like leaching with rainfall and low salinity pre plant irrigation of 150 mm or more (Ayars et.al 1993). Gupta (1990) has shown that EC upto 10 dS/m could be utilized for growing tolerant crops on well drained soils were annual rainfall is more than 400 mm. This is evidence of the fact that the actual suitability of given water for irrigation greatly depends on the relative need and economic benefit compared to other alternatives and on the specific condition of use. Based on the USSL classification the effluent fall under 'good to permissible' category with high salinity and low sodium hazard. (Fig 2 & 3). This indicates that the effluents had more salt concentration and their accumulation on the soil affects infiltration and plant growth in the long run.

Best management practices which are site specific needs to be adopted. The farmer of the region also needs to be educated to adopt suitable practices in the available situation. To avoid salt accumulation leaching and drainage has to be done properly. If necessary subsurface drainage could be installed. Earlier studies have indicated that through drip irrigation the marginal water could be utilized efficiently but care should be taken to prevent the clogging of drips. In case of drip irrigation more area also be irrigated with the effluent water. Selection of crop plays a major role in successful effluent irrigation schemes. Effluent irrigation is encouraged with respect to non consumable crops and landscapping and in some cases with the fodder crops. Another aspect is the crop tolerance and crop rotation. Sugarcane is a tolerant crop and responds well in the effluent irrigation. Reddy et al (1981) has reported sugarcane cultivation with paper mill effluent at Ralgada region of Orissa, India. Sugarcane cultivation using tannery effluent was reported by Kathiresan et al (1998).The Sugarcane mill effluent and distillery effluent for sugarcane cultivation was earlier reported by Nemade (2002).

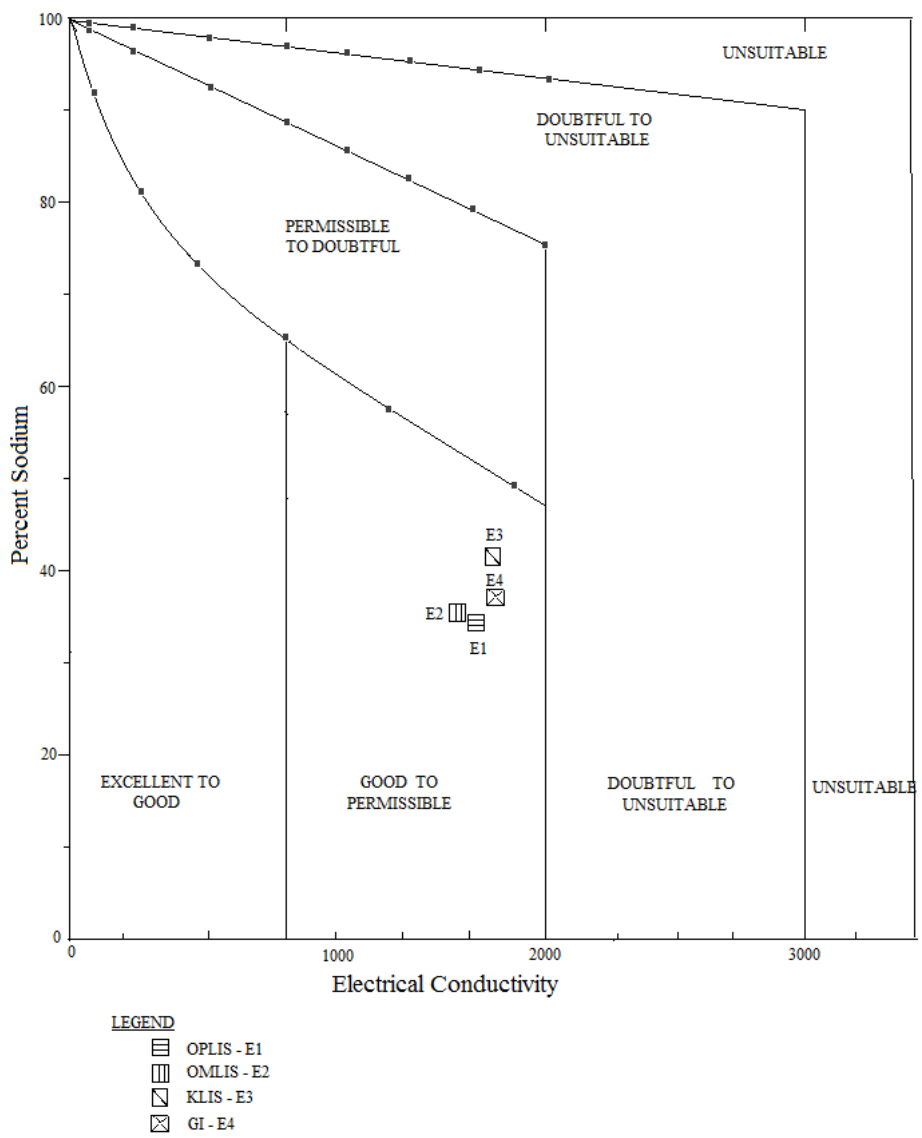

Fig. 2. USSL Plot (Wilcox 1984)

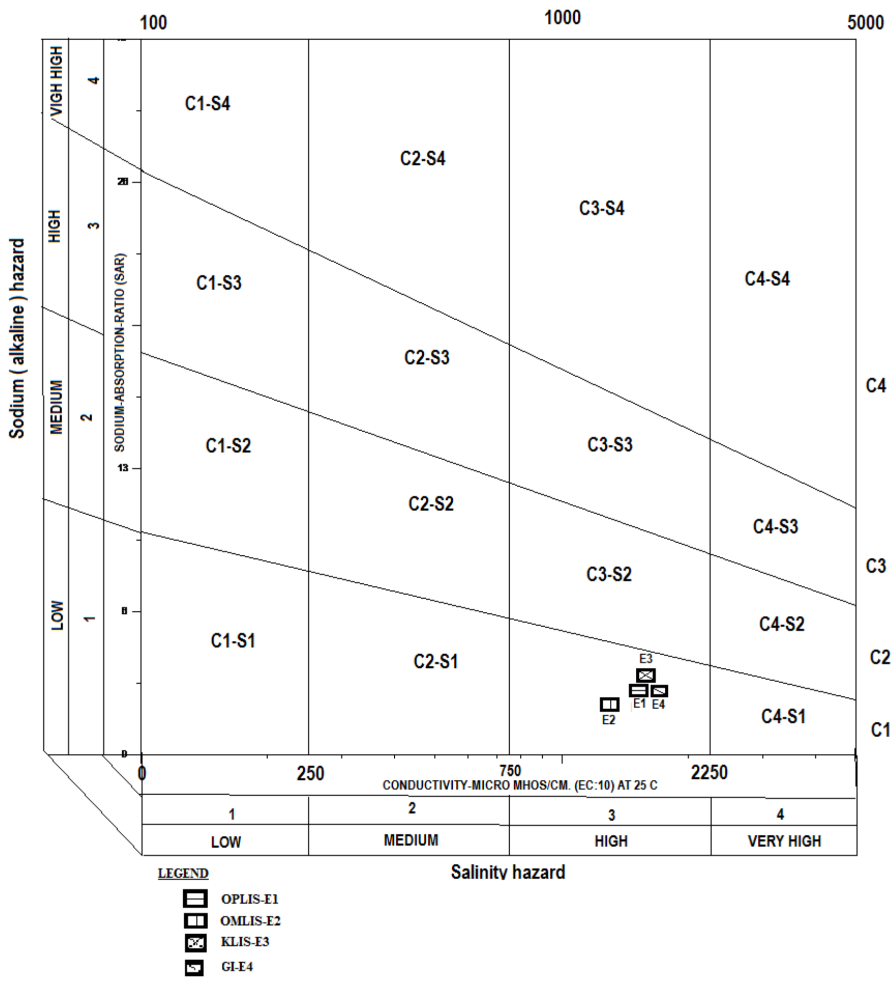

Fig. 3. USSL Plot (Richards 1954)

3.2.2 Sodicity hazard

The sodicity of the irrigation water was determined by sodium percent and sodium adsorption ratio (SAR). The sodium concentration is important in classifying irrigation waters because sodium by the process of base exchange may replace calcium in the soil and thereby reduce the permeability of the soil water. If this process continues it affects the plant growth. From the Table 3, it could be seen that the percent sodium was less than 60, which implies that the paper effluent comes under the category 'good'. Based on SAR, it comes under the low category, as the effluent water collected from different sampling locations registered SAR values less than the 10 and ranged from 2.69 to 3.56.The Kelly's ratio of the effluents collected at all the sample points ranged from 0.62 to 0.82, which is well below unity indicating that the water is free from sodicity hazard.

3.2.3 Alkalinity

The RSC values were negative (Table 3) which means it comes under the category 'Good'. Although CO_3 is much more toxic than bicarbonate and nature of magnesium ions is different than calcium ions, the two anions and cations have been paired together assuming similar effect. In absence of carbonate ions, the bicarbonate does not precipitate Mg. In such cases, Gupta (1984) suggested that alkalinity should be measured using HCO_3 – Ca^{2+} and called as residual carbonate. Care should be taken that these components does not build up in groundwater reserve. Water conservation techniques like artificial recharging the groundwater reserve using the rainwater harvesting structures would be beneficial and helps for the long term sustainability of the programme.

3.2.4 Toxicity

3.2.4.1 Magnesium hazard

The term Magnesium hazard has been used by Paliwal (1972) to evaluate the hazardous effects of Mg to irrigation water and stated that Mg hazard is likely to be developed in the soil when the Mg ratio exceed 0.50. The degree of hazardous effects would increase with increase of Mg / Ca ratio. However, the harmful effect of Mg of irrigation water on the soil is likely to be reduced by the release of Ca on dissolution of $CaCO_3$ if present in the soil (Gupta, 1994). From the Table it could be observed that Mg/Ca ratio in all the effluent samples was less than 0.50 indicating that there was no magnesium hazard in utilizing the mixed effluents for irrigation. Irrigation waters with 0.50 Mg ratio can be safely used for irrigation.

3.2.4.2 Chloride toxicity

Ayers and Brason (1975) proposed the chloride tolerance in waters to be used as an indicator for irrigation purpose. The chloride concentration in the effluents let out for irrigation ranged from 7.91 to 9.90 meq/l which implies that the effluents are permissible for irrigation (Table 3). Gupta (1989) resorted that if the chloride concentration ranges between 4-10 then suitable amendment has to be applied. This again suggests the required amendment and management practice for the long term usage for irrigation. Application of amendments like gypsum and press mud will help in a major way in maintaining the soil health. Alfred et al 1998 identified the press mud and effluent treatment plant sludge as effective ameliorants to overcome salinity due to paper mill effluents. this is because they act as a chealating agent in binding the divalent cation present in paper and pulp effluent.

4. Conclusion

From the aforesaid discussion and interpretation of the chemical quality of the effluent let out for irrigation, it can be concluded that in general the treated paper mill effluents are found to be well within the permissible limits for irrigation. The study further reveals that the quality of the treated effluent falls under the category of 'permissible to suitable' emphasizing the need for better management practices for the long term sustainability of the effluent irrigation programme. The effluents from agro based industries, which use agriculture products as the raw material, and industries, which involved in processing of agricultural products are not detrimental to the environment since the wastes are organic in nature and biodegradable. It is a fact that the suitability of the effluent water for irrigation and the implementation by the farmers is dependant upon the condition of use including crop, climate, soil, irrigation methods and management practices, rather than the water quality classification. Hence better irrigation methods and proper monitoring system will help to minimize the risks and maximize the benefits from this resource. Watershed based impact assessment and conservation strategies needs to be developed, and adopted with the stakeholders participation.

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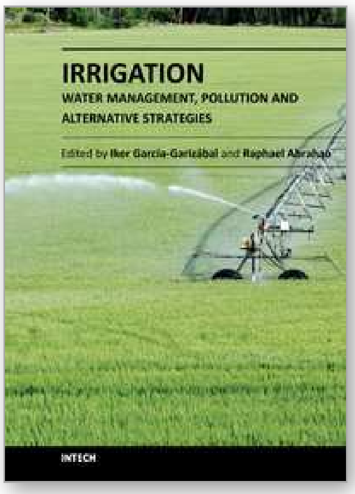

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Irrigated agriculture is the most significant user of fresh water in the world and, due to the large area occupied, is one of the major pollution sources for the water resources. This book comprises 12 chapters that cover different issues and problematics of irrigated agriculture: from water use in different irrigated systems to pollution generated by irrigated agriculture. Moreover, the book also includes chapters that deal with new possibilities of improving irrigation techniques through the reuse of drainage water and wastewater, helping to reduce freshwater extractions. A wide range of issues is herein presented, related to the evaluation of irrigated agriculture impacts and management practices to reduce these impacts on the environment.