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Reuse of Industrial Effluent Water – Prospect and Opportunities in Agricultural Perspectives

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EXECUTIVE SUMMARY

Fresh water is a retreating resource worldwide. To tide over the crisis, limiting its allocation is vivid in every water use sectors. Irrigation occupies a major share of available fresh water to provide food, feed, fodder, fuel and maintaining green space. Only 40% of the total cultivated area is under irrigation and rests are rain-fed. Irrigation water can meet timely water requirement of crop and assure production even during water stress situation. Therefore with growing crisis of freshwater there is a need to provide an alternate source, which could support and sustain production in proportion with growing demand of burgeoning population.

Water quality varies depending on purpose of water – use in various sectors. Agriculture is the major user of water and can accept marginal quality water without apparent loss of productivity or degrading soil and water qualities. A large number of effluent waters are coming out from various industries that could be utilized as per their suitability for agricultural perspectives, which are otherwise reported to defile natural resources and degrading the health of natural ecosystem. Reuse of wastewater for irrigating crops is in vogue since centuries. Due to rapid development and unparallel growth in every sector more and more number of farmers depend on its use especially in developing countries. Most of the effluent reuse practices are not reported to escape the complexities associated with effluent use norms. However the study would help to understand the nature of industrial effluent waters, assess the quality of effluent, locate the applicability of effluent and could promote the use of certain kind of effluent during fresh water crisis for irrigating crops. This has enhanced the scope of using effluent more judiciously in different circumstances to countenance fresh water shortage in agriculture. Keeping this in view a variety of effluents generating from all the major and medium level industries were collected, characterized and investigated for use in irrigation. This bulletin provides comprehensive information about various characters of industrial effluents, merits and demerits and probability of their use in crop production. It has unearthed agricultural potential of certain effluent and their probable use as irrigation source during fresh water scarcity. On consideration of relevant soil characteristics and prevalent land uses, the effort also revealed that how and in what contexts even a

chemically sound industrial effluent water could be used for irrigating crops. Following this the paper mill and distillery spent wash had been used to grow crops at varied situations. Use of them for irrigation in specific soil type appeared to improve crop yield, nutrient uptakes and soil fertility attributes. Evaluation of effluent water from diverse perspectives thus helps to understand their potential and consequently indicate the place of use of individual effluent in specific circumstances. In effluent use practice, periodical regulation of effluent water quality is prerequisite to ensure quality of produce and restore purity of the environment. Selection of effluent quality indicators has thus revealed the state–of–the art to analyze, scrutinize and condense the characteristics to indicating properties. Estimation of these indicators only could reflect the character of effluent when use for irrigation and could save energy, cost and time to a great extent. It also indicates about the necessary measures to be undertaken to secure soil and crop qualities as well. Development of this environs – friendly package thus provides effluent water reuse techniques and information for promoting its reasonable use in farming.

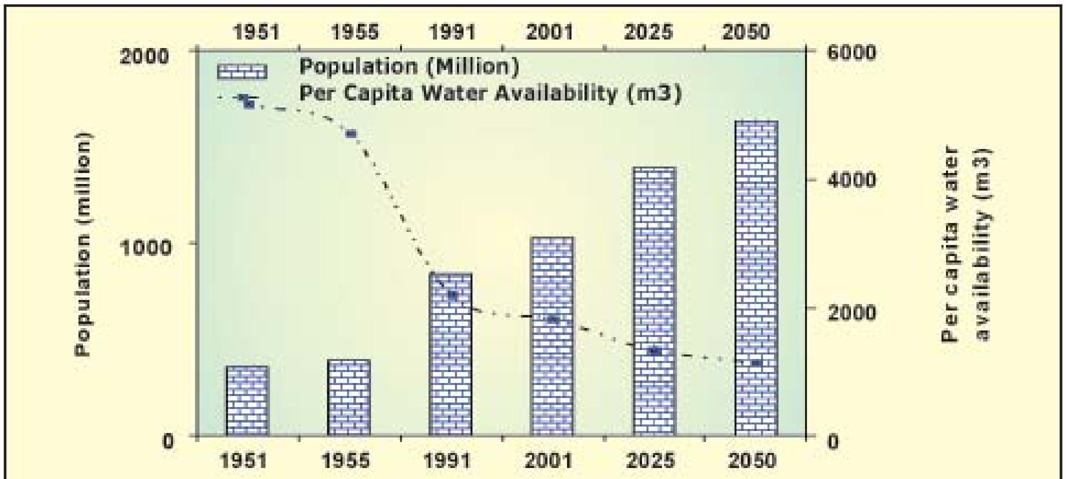
1. INTRODUCTION

With rapid population growth, urbanization and industrialization, wastewater generation is getting enlarged and caused environmental nuisance if not properly treated before discharge. In many developing countries, wastewater treatment plant is insufficient with respect to volume of wastewater generated. Owing to that waste / effluent water reuse is viewed increasingly as a means to augment existing water resource in many water-starved areas.

Fresh water is a dwindling resource worldwide. Retreating high quality waters is a serious issue for temporary, semi – permanent and permanent kind of water – scarce regions. Many more countries will become water – stressed because of increasing water scarcity in coming era (Seckler et al. 1998, FAO 2003). Consumption of fresh water is much higher than its replenishment process. A steady recession of its allocation is evident in every water consumption sectors including agriculture where water is an integral component. An exponential decrease of par capita availability of water is marked with rising population in India (Fig.1). The sector – wise allocation of water is progressively increasing with population in domestic/livestock and industrial fronts while a quadratic decrease is marked in agricultural irrigation (Table 1). The population induced water scarcity is thus an impending reality in this sector (Fig 2). Irrigated agriculture is one of the major water consumers across the country. It uses 85% of the country's total available fresh water resources. The irrigation water provides an assured water supply for standing crops that ensures crop produce by alleviating uncertainty in any agro-climatic zone. Profitable agriculture is always reliant on irrigation. Therefore under steady decrease of irrigation water volume there is an urgency to have an alternate source that can mitigate fresh water deficiency and sustain production. It is therefore high time to look towards wastewater / effluents because agriculture can accept inferior quality water than domestic and industrial uses.

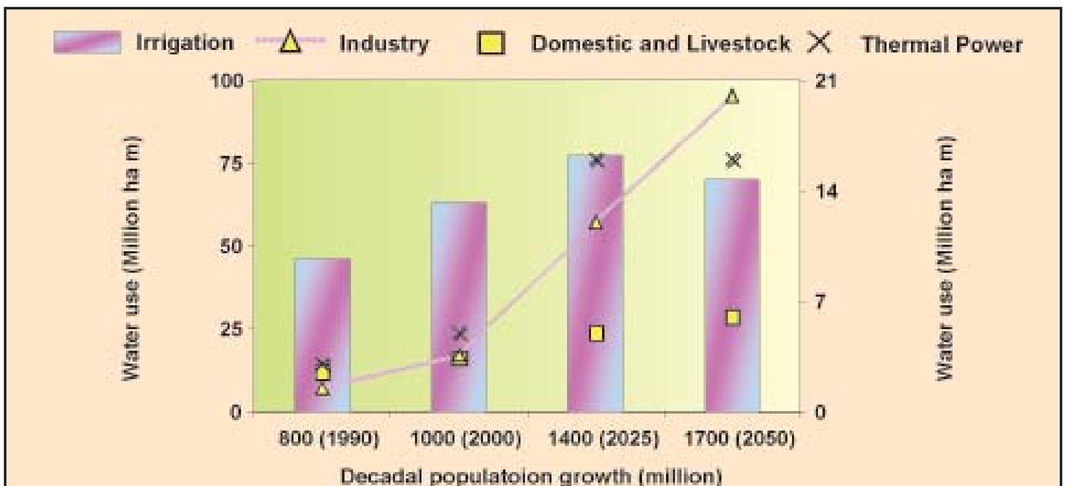
The character of industrial effluents profoundly varies, determined by type of product, nature of inputs involved, effluent treatment processes and capacity of industrial unit. Reuse of this water is always associated with advantages and disadvantages. Apart from supplying water, its organic and inorganic constituents could meet nutrients' requirement of crops, decrease the fertilizer / manure requirement, improve soil fertility and simultaneously enhances the chances of contaminating soil, water and producing degraded quality crops (Ensink et al. 2002, Qadir and Schubert 2002). So health and environment are the two important aspects that need utmost care under effluent reuse options, because no effluent should be used or accepted for use unless it safely applies (Gerba and Rose 2003, Salgot et al. 2003). Notwithstanding the use of wastewater may not be a choice for many farmers instead becomes a reality in forthcoming future. Consumption of industrial effluent in agriculture may reduce the risk of contaminating soil and water resources by releasing effluent in the environment.

Prior to put it into practice in - depth knowledge on quality of every effluent is prerequisite. Characterization of industrial effluent would reveal the potential of effluent while evaluation of it reflects its quality that could be exploited by thorough planning and management for agricultural perspectives. However safe use of effluent in crop production is indispensable. To preach, propagate and promote the safe use of industrial effluent, the present compilation provides details of a variety of industrial effluents, thoroughly analyzed their properties from different viewpoints, reflects their virtues and vices, reveals the applicability of different effluents and assess the impact of effluent use in cropping.



(Source : http://www.indiastat.com/india/ShowDataSec.asp?secid=365176&ptid=18198)

Fig 1: Variation of water availability with population growth



Source: Water and Related Statistics, March 2002, Central Water Commission.

Fig 2: Changes of water use pattern with population growth in various sectors

2. AVAILABILITY OF INDUSTRIAL EFFLUENT

2.1 Sources of industrial effluent

Table 1: Projected water demand of various water users in past, present and future in India (Unit: Billion Cubic Meters)

Sector	*1990*	*2000*	*2010*	*2025*	*2050 (Provisional)*
Domestic	32	42	56	73	10
Drinking (incl. live stock)	-	-	56	73	-
Irrigation	437	541	688	910	1072
Industry	-	8	12	23	63
Energy	-	2	5	15	130
Other	33	41	52	72	80
Total	**502**	**634**	**813**	**1093**	**1447**

Aqueous waste which generates from industrial processes is termed as industrial effluent. The amount varies with type of industry and nature of practice. For example around 175 m^3 effluent per tonne of paper produced is emerging out from paper mill while it is 12 m^3 per KL of alcohol produced. But for cane crushing only 0.4 m^3 is produced per tones of cane crushed. From steel industry, 16 m^3 is coming out per tonne of finished steel and 100 – 500 m^3 is emerging out per tones of fibre processed or finished products from textile industry.

2.2 Current status of industrial effluent

Industry uses 22% of global water reserve (UN World water development report 2003) and releases a huge amount of wastewater in the environment. In India, around 391.7 MLD effluent water is being generated from five states viz. Andhra Pradesh, Gujarat, Karnataka, Maharastra and West Bengal (CPCB, 2000). Data for other twenty three states are not available. The effluent inevitably ends up at surface or in underground water – bodies, adversely change water quality, endanger environmental purity, which otherwise could be used if proved suitable for agriculture. Effluents are also being recycled by the industries. It is a cost intensive option and hence unable to pursue by many medium and small scale industrial units. Due to that even a small portion of effluent if found utilizable in agriculture that would be useful for the industries. In other words agriculture gets benefited by alternate water source as well during reeling scarcity of fresh water. Reuse of industrial effluents, however is associated with the risk of contaminating soil, crop and water courses chiefly by metals / heavy metals. Astute management practices can ameliorate the risk and promote its use in this sector

A slice of NTPC at Talcher

Unfavorable destination of effluent water
at Anugul industrial belt

3. QUALITY OF EFFLUENT WATER

Effluent water quality includes those biological, chemical and physical parameters to illustrate its ability for use in intending purpose. Use of it for irrigation also takes in account of soil and crop health that need to be protected from deterioration. Realizing the relevance of chemical properties of water in crop irrigation the chemical profile of the industrial effluents was assessed and their possible use in specific circumstances were worked out.

3.1 Compositions of effluent

The chemical compositions of industrial effluent starkly vary, depending on type of industry, nature of produce, quality of inputs, effluent treatment facilities and the alike. Possibility of presence of various substances in the water is thus large which to be appraised to ascertain their safe use wherever appropriate. Forty – four numbers of effluent waters representing twenty different kind of major and medium industries were collected and characterized by 23 chemical properties. Industries are located at various places in Orissa and belonged to seven principal categories. (Table 2)

Table 2: Type of industries which were covered for effluent analyses in Orissa

Sl. No.	Industrial category	No. of effluent collected
1	Pulp and paper	3
2	Chemicals and Fertilizer	17
3	Fermentation and the like	7
4	Oil hydrogenation unit	4
5	Thermal power	2
6	Ferro alloys and ore beneficiation plant	7
7	Iron and steel	4
	Total	**44**

Among the chemical components, EC identified 61% as non saline and 9 – 11% as highly saline. In respect of pH, 9 – 4.4% industrial effluents were strong to moderately acidic; 34 and 11% were moderately alkaline and highly alkaline in reaction while pH and RSC together determined 9% as strongly alkaline. Around 4.54% effluent had Mg/Ca > 3.0 with EC > 5.0 dS/m. Sulfate preceded by chloride ion concentration except in 6.82% samples. Around 6.82% sample had B > 5.0 mg/l. Nitrate ranged from 0.58 – 11.4 mg/l with highest concentration obtained from ash pond water (Thermal Power Plant) followed by 'Paper mill' discharge. Dissolved organic matter changed between very low to 100 mg/l. This evidently reflects the striking variability of industrial effluent properties, quality and subsequently indicates the need of requisite acumen and experience for its evaluation to use in farming.

3.2 *Merits and demerits of effluent*

Use of industrial effluent in cropping depends on several factors such as site specific information on soil, climate, crop type, physical land form and mode of application. This multi – faceted character of the factors opens up the prospect of using effluent at different contexts. With precise information, careful planning, complex management practices and highly stringent monitoring procedures, effluent could be profitably utilized under specific circumstances / landscape (Scott et al. 2004). A wide variety of water reuse policies depending on socio-economic circumstances, institutional and technological conditions are available (USEPA 2002) though not complied with by many countries. Because most effluent water using countries are in lack of machineries and technical incompetence to monitor the pollutants' concentration. Nonetheless effluent reuse in agriculture is an impending reality and essential in developing countries particularly India, where irrigation requirement is large. Different approaches of effluent reuse considering irrigation water quality criteria / relevant soil characteristics / land – forms, in agriculture were developed. Step by step the methodologies uncover the actual potential of effluent indicates and the prospect of its use in agriculture.

4. APPROACHES OF EFFLUENT WATER REUSE IN AGRICULTURE

In sub-humid Orissa, agriculture solely depends on monsoon. Owing to that agricultural production widely fluctuates from year to year, severely suffers by vagaries of monsoon though the state receives good amount of rainfall (mean 1200 to 1800 mm) per annum. Around 26.96 lakh hectares irrigation potential has been created by the end of 2004-05. Of this 12.37 lakh hectares are irrigated through major and medium irrigation projects, 8.8 lakh hectares through minor and the rest through private tanks, ponds, dug – wells and water harvesting structures etc. Assured water available through major and medium irrigation projects covers only 45.87% of the total area under irrigation. It needs to augment substantially because assured irrigation provides support and ascertain crop production irrespective of erratic monsoon (Orissa Government Economic Survey, 2006)

4.1 *Irrigation potential evaluation approach*

On the basis of pH ≥ 8.5 scale and residual sodium carbonate (RSC) ≥ 2.5 mmol/l status, the alkalinity of effluent water can be estimated (USSL 1954) while EC > 4.0 dS/m (Das 1998) and SAR, 10 $(mmol/l)^{0.5}$ recommended by ICAR – AICRP report (1990) offering tool to assess salinity / salt stress of the effluent. Expression of SAR $\left(Na/\sqrt{(Ca+Mg)12}\right)$ sometimes underestimates Na – hazard and permeability problem in soil, the adj.R_{Na} (adjusted SAR) was therefore introduced (Suarez 1981) to estimate the hazard and refine its use in agriculture. In addition to Ca/Mg is also proved important to adjudge the suitability of effluent for use in irrigation. Recommended level of the ratio should below 1.0 for effective use of water as suggested by Minhas and Gupta (1992). Besides Mg/Ca ratio if greater than 1.0) with Ca concentration 1-2 meq/l then the water is considered sub – lethal and thus found good for use in irrigation. Excess concentration of sulfate (SO_4^{2-}) over chloride (Cl^-) ion is beneficial for irrigation because the latter develops much higher salt stress for plants' root than the SO_4^{2-} ion induced salinity (Minhas and Gupta 1992). Growing pulses with SO_4^{2-} enriched irrigation water was found beneficial by partial fulfillment of sulfur nutrition of the crop (Manchanda 1990). Occurrence of B, F^- and NO_3^- ions in industrial effluent depends on type, quality of raw materials and methods of processing followed by various industries. Nitrate ion enriched water should be considered as nitrogen – source by meeting the requirement of an essential crop nutrient through irrigation (Manchanda 1990). Excess NO_3^- concentration may cause overgrowth, delaying maturity and decrease crop yield but its critical concentration level below which the excess plant growth can be abated, is not adequately delivered. The effluents also contained plant nutrients e.g. phosphorous (P), potassium (K), boron (B), zinc (Zn), sulfur (S) etc in various amount, which could be exploited for crop growth through right planning of reuse and management.

The threshold concentration levels of F^- ion in irrigation water varies. It is 1.0 mg/l suggested by Ayers and Westcot (1985) while 10 mg/l is recommended by Gupta (2001). Threshold concentration level of element determines by multiple factors like soil type, climate and nature of crop to be grown under specific circumstances, and thus it differs from location to location. Since F^- is a strong hydrophilic ion and hence application of F^- rich water in acidic soil needs to scrutinize thoroughly. Likewise presence of Fe, Cr, Pb, Cd or other heavy elements will also be compared with their respective prescribed limits (Ayers and Westcot 1985) and the suitability of the effluent will be perceived. Besides Fe, pH and total dissolved solids (TDS >2000 mg/l) are required to consider together to find out the suitability of effluent for use in drip irrigation. In this way the agricultural potential of the effluent could be uncovered and recognized. In a study conducted with twenty different industrial units, located in Orissa, the effluents of paper mill, fermentation (breweries and distilleries) and sugar factory are found usable, while the effluents of rubber and fertilizer units have shown usable with slight to moderate degree of precautions for irrigation.

4.2 Soil characteristics based approach

On consideration of salient soil properties such as pH, texture, organic matter and readily available N, P, K contents, the soil based feasibility of effluent use can be assessed. Take an example of Orissa, the whole state is covered by eight major soil types (Gangopadhyay 1991, NBSS & LUP 1998). Each soil type has certain assets and also liabilities. If the liabilities get conditioned by effluents' potentials and assets by effluents' liabilities, then the effluents could primarily be considered for use in agricultural purpose. Such as red and laterite soils, where excess presence of ferruginous nodules is the major constraint, where acidic effluent with high Fe and F^- contents is not feasible for use in this soil. Acidity can aggravate the activity of Fe and F^- ions and creating a situation unfavorable for crop growth. Likewise for saline and alluvium soils which are prevalent in coastal Orissa, effluent containing high soluble salts needs to be avoided. In this way the soil based preferences for receiving effluent could be perceived.

Relevant soil characteristics like pH, EC, texture, organic matter and N, P, K contents were jointly compared with pH, salinity, sodium adsorption ratio, carbonate and bicarbonate, iron, fluoride, sulfate, cadmium, chromium and lead contents of effluent. If the effluent was not favored by soil in any one of those parameters then rest others was not considered, and the effluent was declared unfit for agricultural use. The effluent characteristics were treated as key attributes due to their irreversible and severity of impact on soil health. Subsequently the Ca/Mg ratio, NO_3^-, B, DOM, and TDS contents of effluent were considered for comparison and as per recurrent appearance of effluent against each soil type, two distinct classes of fitness viz. A – Preferred and B – Moderately preferred were formed (Table 3).

4.3 Groundwater development status based approach

In many regions of the World, groundwater development has already attained to a level to restrain its expansion further, where soil based effluent utilization approach could give an alternative and may ease the pressure on already exhausted groundwater resource. Effluent use prospect can also promote the use of multi – quality water resources in conjunctive mode. As such the groundwater development status in Orissa is 21%, which is far below the level that requires attention though it widely varies from place to places. Such as in Baleswar, Bhadrak, Jajpur and Kendrapada districts the groundwater development has already reached 60% (State Groundwater Board report 2001), precisely it touched $\cong$ 60% level (termed as 'grey zone') in six blocks and 70 – 75% (intense grey zone) in two blocks of those four districts (Table 4). This strongly disallows it's anymore development at present. These places are differed in physiographic features and soil types. Applying soil based approach for receiving effluent suiting to local contexts, the location-wise probable pattern of effluent reuse was perceived. It could reduce the load on underground aquifer and offer an apparent irrigation source as well. In addition to, this approach also expands the scope of practicing conjunctive use of effluent and groundwater, which presumably helps in augmenting cropping intensity without laying extra burden on overexploited groundwater sources.

The usefulness of paper mill, sugar mill, fermentation (breweries and distilleries), marine shrimp processing unit and rubber goods manufacturing industries effluents are also evident in this approach. But field level assessment of these effluents is required for perfection and optimizing the amount with respect to crops and soil types.

Table 3: Soil types and their preferences for receiving effluents

Soil type	Salient soil characteristics		Soil based preference of effluents for agricultural uses
	Potentials	Constraints	
Red sandy and loamy: a. Lateritic b. Red & Yellow soil of hilly terrain	No salinity, well drained and high permeability	Acidity, Fe- oxides and P-fixation Hydrated Fe & Al oxides, acidity, Fe – nodules	**A** – Paper mill, sugar mill, , marine shrimp processing, rubber goods manufacturing industries, **B** – *Captive power plant, Ispat alloys
Red and Yellow soil of fine texture	Low permeability	Hydrated Fe & Al oxides, acidity, Fe – nodules	**A** – Paper mill, sugar mill, marine shrimp processing, rubber goods manufacturing industries **B** – *Captive power plant, Ispat alloys
Coastal alluvial soil	Neutral in reaction	Excess presence of soluble salts	**A** – Paper mill, fermentation, *captive power plant, urea fertilizer, heavy water plant , Fe – Mn Plant, **B** – Galvanizing, rubber goods manufacturing industries, ore beneficiation unit
Deltaic alluvium with coarse	Slightly acidic to neutral in	No apparent liabilities	**A** – Paper mill, fermentation, *captive power plant, urea fertilizer, heavy water plant, marine shrimp processing, texture reaction rubber

			goods anufacturing industries, Ferro alloys, Ore beneficiation unit, **B** – DAP fertilizer units
Deltaic alluvium with fine texture	Do	Restricted soil water flow	**A** – Paper mill, sugar mill, aluminum smelter, urea - fertilizer, heavy water plant, marine shrimp processing, rubber goods manufacturing industries, Fe - Mn Plant **B** – DAP fertilizer units, fermentation
Black soil	High water holding capacity	Deep crack in summer	**A** – Paper mill, sugar mill, marine shrimp processing **B** – Fermentation, rubber goods manufacturing industries, Fe – Mn Plant, cosmetics, ore beneficiation unit, aluminum smelter
Mixed red & black soil	No salinity, high water holding capacity	Acidity, Fe- oxides and P-fixation, soil cracking in summer	**A** – Paper mill, sugar mill, urea – fertilizer, heavy water plant, marine shrimp processing, Indian rare earth, Fe – Mn Plant, Ore beneficiation unit **B** – Fermentation, *captive Power plant, rubber goods manufacturing industries
Brown forest soil	Irrigation is usually not required except to establish nursery plantation		Paper mill, fermentation, *captive power plant, aluminum smelter, marine shrimp processing, Indian rare earth, rubber industries, ore benefaction unit, Ferro alloy

*Coal based thermal power plant generates electricity and the water which uses for cooling the tower is considered the wastewater of that plant

Note: Indian rare earth – effluent was found good for use in irrigation but the amount was too small to use and so it was not taken into consideration for use

Table 4: Groundwater development status-wise effluent use prospect in different districts

District name and no. of blocks	Groundwater development % at block level	Dominant physical region	Soil type	Characteristics	Suggested classes of effluents
Balasore, 9	50 - >70	Utkal plain and Mahanadi delta	Coastal alluvium	Presence of fair amount of Ca, Mg, Na, K and salts, neutral in reaction	A - Paper mill, fermentation, captive power plant B - Galvanizing unit, rubber goods manufacturing industries
			Deltaic alluvium	Slightly acidic to neutral in reaction	A - Paper mill, sugar mill, marine shrimp processing B - Fermentation
Bhadrak, 2, Jagatsingpur,1, Kendrapara, 1	60 - >70 50 - 60 60 - 70	Mahanadi delta	Deltaic alluvium with coarse and fine texture	Deficient in N, P and sometime K, slightly acidic to neutral in reaction	A - Paper mill, fermentation, sugar mill, marine shrimp processing, rubber goods manufacturing industries
Ganjam, 2	50 - 60	Utkal plane alluvium	Coastal and deltaic	Contain fair amount of Ca, Mg, Na, K and salts, neutral in reaction	A - Paper mill, fermentation, captive power plant B - Galvanizing unit, rubber goods manufacturing industries
				Slightly acidic to neutral in reaction	A - Paper mill, sugar mill, marine shrimp processing, B - Fermentation
Cuttack, 1, Jajpur, 2	50 - 60 50 - 70	Garjhat Hills and	Laterite and red soil	Shallow depth, low AWC*, fine loamy, optimum drainage, low fertility and acidity	A - Paper mill, sugar mill B - Captive power plant
		Mahanadi delta	Deltaic alluvium with coarse and fine texture	Deficient in N, P and sometime K, slightly acidic to neutral in reaction	A - Paper mill, fermentation, sugar mill, marine shrimp processing, rubber goods manufacturing industries

The potential of different nature of industrial effluents is thus gradually unraveled, recognized and defined the area of its applicability in agricultural perspectives (Fig 3). These substantially help to understand effluent water quality and consequently its use or no-use could be estimated.

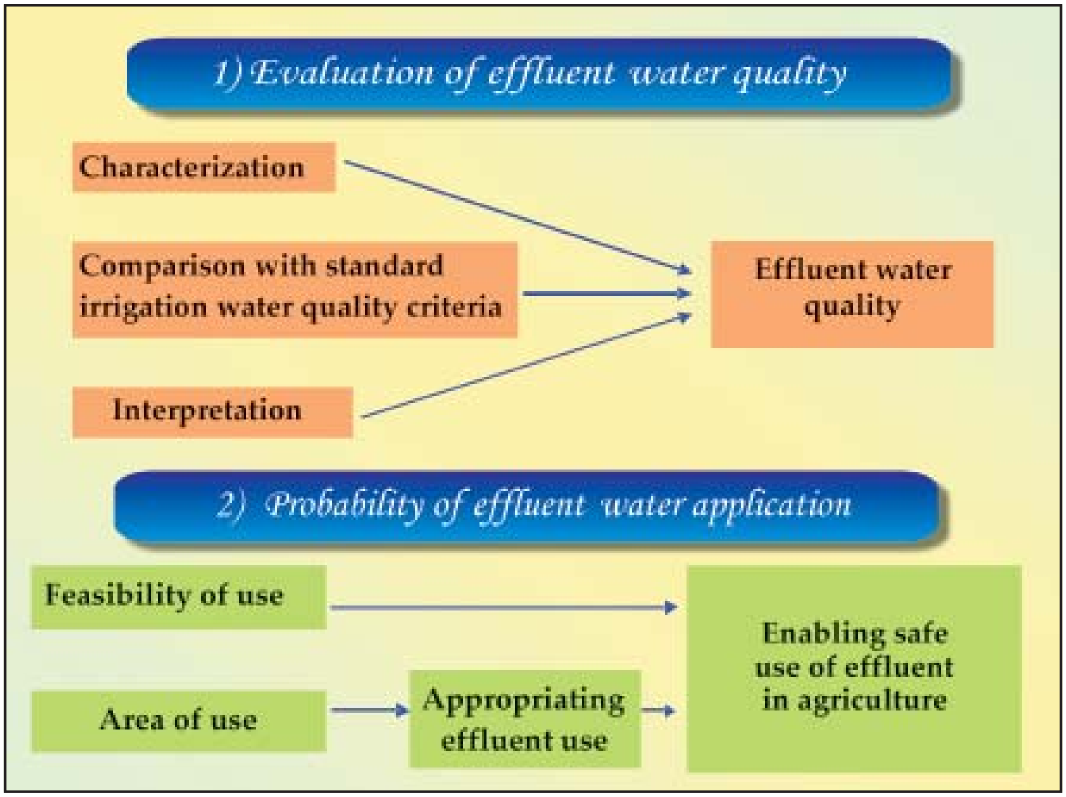


Fig 3: Evaluation of effluent water for reuse in agriculture

5. MONITORING EFFLUENT WATER QUALITY DURING REUSE

In effluent reuse proposition monitoring effluent quality is crucial to ensure its safe use in agriculture. The use of wastewater in crop production possess some risks to damage the pristine nature of soil and water resources, health of the consumers and handlers, hence periodical monitoring of wastewater quality during its use is imperative. This needs to estimate a variety of effluent quality attributes. The procedure is cumbersome, cost effective and also time consuming. However these can be simplified if effluent quality indicators are known and available for use. Indicator is the measurable properties of effluent quality that reflect the health of effluent to support crop growth and restore environmental and ecological purity. A comprehensive knowledge on effluent water quality specific to use in crop irrigation is therefore imperative. Identification of effluent quality indicators is indispensable because periodical monitoring of a wide range of parameters and interpret on the basis of parameter by parameter analysis is difficult and also tedious to carry on. During past decades, the most prevalent water quality research theme has thus focused on water quality indicator selection and evaluation.

5.1 Principal component analysis

Multivariate technique is useful for analysis of a large number of variables. It reduces dimensionality of the data, produces easily interpretable results without important loss of information. The principal component analysis (PCA), factor analysis and discriminant analysis have been success-fully utilized in hydrochemistry since long. The multi-component techniques were employed for quality assessment of surface water (Vega et al., 1998; Wunderlin et al., 2001; Simeonov et al., 2003), groundwater (Reghunath et al., 2002), and also in environmental research (Bartolomeo et al., 2004; Lambrakis et al., 2004). Discriminant analysis is applied increasingly in agronomy because of its capacity to analyze correlations between two groups of variables simultaneously (James and McCulloch, 1990; Doledec and Chessel, 1994). It helps to organize complex data sets, describing the variation in data sets and generating the possible causes of the association identified.

In Principal component analysis (PCA) a large number of correlated characteristics are reduced to uncorrelated factors that are linear functions of the original characteristics. It helps to group a no. of effluent characteristics into statistical factors based on their correlation structure (Knudson et al., 1977; Norusis, 2000). Each factor is responsible for the correlation among the group of parameters that comprised it. Then the analysis was performed on standardized parameters using the correlation matrix to eliminate the effect of different measurement units on the determination of factor loadings (Brejda *et a*l., 2000 a, b; Norusis, 2000). Factor loadings, i.e., the simple correlation between the effluent characteristics and each factor, show how strongly a characteristic expresses the general meaning of the factor.

Eigenvalues are the amount of variance explained by each factor. Factors with eigenvalues > 1 explain more total variation in the data than individual effluent characteristics. To maximize the correlations between PCs and variables, the variables are subjected to different rotations. Factors with eigenvalues >1 contributing >5% variability within the measured data and contain at least three variables with high loadings are used to retain (Velicer and Fava, 1998).

5.2 Discriminant analysis

Discriminant analysis is used to select the statistical factors that are most discriminating between the retained factors to address the quality of effluent. In effluent reuse perspectives the cases can be classified with ‘probability of effluent use in irrigation’ as the grouping variable within – group covariance matrix. On the basis of level of significance (Wilks' lambda method) the discriminnt function can be selected.

Effluents could be grouped as per their 'probability of use' in irrigation. In the grouping process the relevant properties of effluent need to compare with their corresponding threshold limits, suggested by different standard irrigation water quality guidelines (Ayers and Westcot 1985, BIS 1986, Mihas and Gupta 1992, Singh *et al.*, 1996 and Das 1998). Based on prevalent agro-climatic situation and actual environment where the effluent reuse will be practiced, different guidelines need to be chosen to interpret the suitability of effluent for use in irrigation. Ensuring environmental quality the guidelines formulated by EPA (1986) and Ministry of Environment and Forests are available for using effluent in agriculture. These have given an overall effluent quality appraisal for reuse purpose. But for irrigation use perspective, comparison of every effluent property with irrigation water quality criteria is essential to reveal the precise nature of effluent. A step – wise comparison process is always helpful to disclose nitty-gritty of the effluent and eventually indicate its area of use in appropriate manner.

5.3 Identification of indicators

In multivariate methods discriminant analysis can be used for factors or principal components to identify the most influential factors and then for factors' components to identify their magnitude of importance for expressing effluent quality. The components are nothing but the characteristics of effluent and could be treated as effluent quality indicators for particular uses. The discriminant analysis resulted into discriminant functions where the magnitude of discriminant coefficients of corresponding factors or components indicates its level of importance to a specific purpose.

In a study conducted in Orissa, multivariate analysis of 23 chemical characteristics of 44 nos. of different industrial effluent extracted four statistical factors and discriminant analysis of the factors resulted into following discriminant function:

$$Z = 0.887 * \text{salt type} + 0.86 * \text{salinity} - 0.199 * \text{heavy metal} + 0.187 * \text{K– factor} \qquad (1)$$

Principal component analysis indicated that the 'salt type factor' was the most influential factor as it explained 20% of the variance of effluent characteristics followed by 'salinity factor', which constituted 17.8% of the total variance (Fig 4). The importance of the 'salt type factor' is corroborated by the discriminant analysis. The discriminant coefficient for this factor was 1.03 to 4.74 fold larger than the coefficients of salinity and K – factors (Eq. 1). Difference of discriminant coefficients of salt type from salinity factors was smallest and getting larger progressively from salinity to K – factors in proportion with their % estimates of total variances (Table 6). It clearly indicates that the salt type is the most promising factor in discriminating among different effluent discharging industrial units.

Discriminant analysis of effluent attributes which formed ‘salt type’ ‘salt stress’ and ‘heavy metal impact’ factors resulted to different discriminant functions respectively, which are given below:

$$Y1 = 1.622*TDS – 1.293*Mg + 1.103*Cl^{-} + 0.729*Fe – 0.263*B – 0.159*Ca \quad (2)$$

$$Y2 = 1.074*EC + 1.024*Na – 0.973* SAR – 0.453*pH \quad (3)$$

$$Y3 = 6.394*Pb – 5.701*Cd – 0.518*Cr \quad (4)$$

Of all discriminant coefficients vivid in functions 2, 3 and 4, largest was found for Pb and Cd followed by TDS and Mg and thus reflects their level of importance to determine effluent quality for agricultural uses. In terms of magnitude of discriminant coefficients, the significance level of EC, Na, SAR, Cl and Fe for determining effluent quality was at par. In discriminant function 2, TDS and Mg have large coefficient value, which also substantiated by high loading values under ‘salt type’ factor (Fig. 4). Function wise the level of magnitude of discriminant coefficient has rated TDS as most discriminating variable followed by Mg > Ca in (2), EC>Na> SAR in (3) and Pb>Cd>Cr in (4). But with decreasing magnitude, the overall trend is Pb> Cd>>TDS> Mg ≅ Cl ≅ EC ≅ Na > Fe ≅ SAR > Cr ≅ pH and rest others. With respect to estimate of discriminant coefficient, the contribution of Mg (1.293), Cl (1.103), EC (1.074) and Na (1.024) content is appeared at par while the difference between Fe and SAR, and Cr and pH is marginal. The importance of Ca was not reflected despite its high loading value that may be attributed to the relatively less variable nature of Ca (Table 7). Variability thus indicates the sensitivity vis-à-vis significance of the variable to determine the quality of effluent to use for a specific purpose.

5.3.1 Variance analysis

Variance analysis reveals the sensitivity of effluent attributes change with the type of industrial units. This sensitivity towards variability should be reflected by effluent quality indicators. Thus the extent of variation presents in effluent attributes need to determine and based on coefficient of variation (CV) the attributes are used to classify into different variability classes. Indicator with high CV and relative range (RR i.e. the ratio of range and mean) suggests that it is relatively sensitive to change with type of industry.

Variance in effluent attribute depends on several factors such as type of industry, nature of input materials, kind of output and treatment processes the industry used to follow and the like. Attributes under high variability class (Table 5) indicate their excessive sensitivity to vary with industry type and consequently reveal their significance to serve as indicators for apprising effluent quality for irrigation use.

Among the discriminating variables TDS, Mg, Cl, Na, Fe, SAR, Cr are extensively varied (CV, 210 – 446% and RR, 11 – 28.7), Pb, Cd and EC are moderately varied (CV,

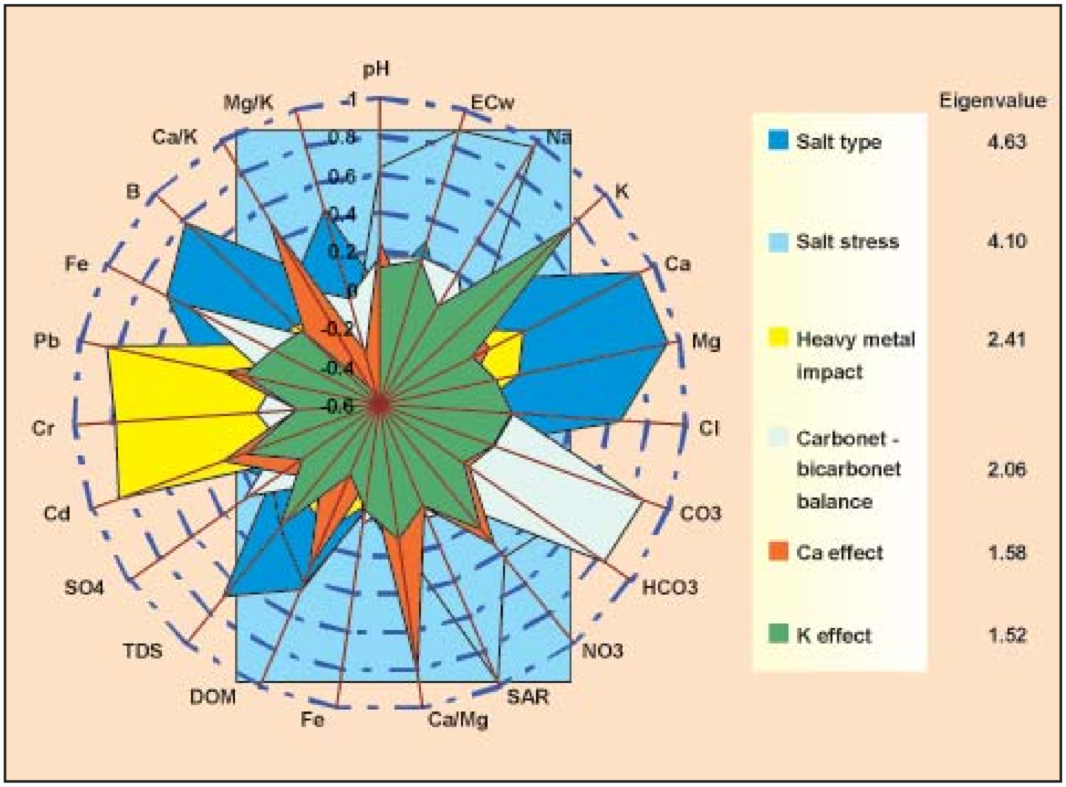


Fig 4: Factor loadings of different water quality factors derived from rotated Principal Component Analysis

175 – 197% and RR, 3.5 – 9) while lowest variability is marked in pH (Table 5). High CV with high RR indicates more variability than high CV with moderate / low RR value as observed in DOM content (Table 5). Combining variability (as a measure of sensitivity) with the result of discriminant analyses, the overall order of significance of effluent attributes is Pb > Cd >> TDS > Mg. Chromium and pH are found as least important properties.

Out of fourteen variables of high variability class (Table 5), four attributes Mg, SAR, Na, TDS revealed their significance to act as effluent quality indicators. Lead, Cd and Cr are heavy element, so their amount of presence in effluent needs to monitor for securing quality of produce and protecting soil and groundwater health from contamination. The Mg content reflects hardness of effluent that affects dispersion of soil structure if exceeds certain critical concentration level while SAR and Na divulge the gravity of Na hazards after application in soil. Integration of the results of PCA and DA with variance analysis, the Pb, Cd, Mg, and Cr have emerged as first line indicators followed by TDS, Na, SAR, Fe and pH as second line indicators for evaluating and monitoring the quality of effluent during use for irrigation.

Table 5. Variability estimates of different effluent quality attributes (sorted by CV%)

Effluent attributes	Range	Mean	SD	CV %	RR
High variability (CV ≥ 400% – 200%))					
Cr mg/l	0.44	0.02	0.09	446.27	21.46
CO_3^{2-} me/l	297.92	10.42	46.39	445.22	28.59
Mg me/l	153.85	5.36	23.05	429.93	28.69
SO_4^{2-} me/l	15.92	0.64	2.58	401.49	24.81
F^- mg/l	212.13	10.62	42.54	400.47	19.97
Fe mg/l	0.95	0.06	0.22	372.49	16.39
SAR $(me/l)^{0.5}$	119.97	5.80	20.10	346.51	20.68
Na me/l	119.96	7.01	22.14	315.64	17.10
HCO_3^- me/l	272.15	13.21	41.51	314.30	20.61
B mg/l	41.78	2.86	7.94	277.41	14.59
TDS gm/l	18.20	1.61	4.00	247.77	11.27
Ca me/l	50.77	3.62	8.13	224.33	14.01
DOM mg/l	99.00	14.52	30.82	212.30	6.82
Cl^- me/l	59.50	5.09	10.70	210.19	11.69
Moderate variability (CV ≥ 200 – 100 %)					
Pb mg/l	0.58	0.11	0.22	197.17	5.18
EC dS/m	25.05	2.83	5.53	195.62	8.85
Cd mg/l	0.05	0.01	0.03	194.66	3.48
K me/l	4.24	0.56	0.97	174.78	7.60
Mg/K	85.14	15.98	21.25	132.98	5.33
Ca/K	102.43	19.15	22.79	119.04	5.35
Low variability (CV < 100%)					
NO_3^- mg/l	11.10	3.19	3.01	94.45	3.48
Ca/Mg	6.44	2.24	1.77	78.91	2.87
pH	8.78	7.61	1.78	23.41	1.15

6. EXPERIENCES OF INDUSTRIAL EFFLUENT REUSE IN CROP PRODUCTION

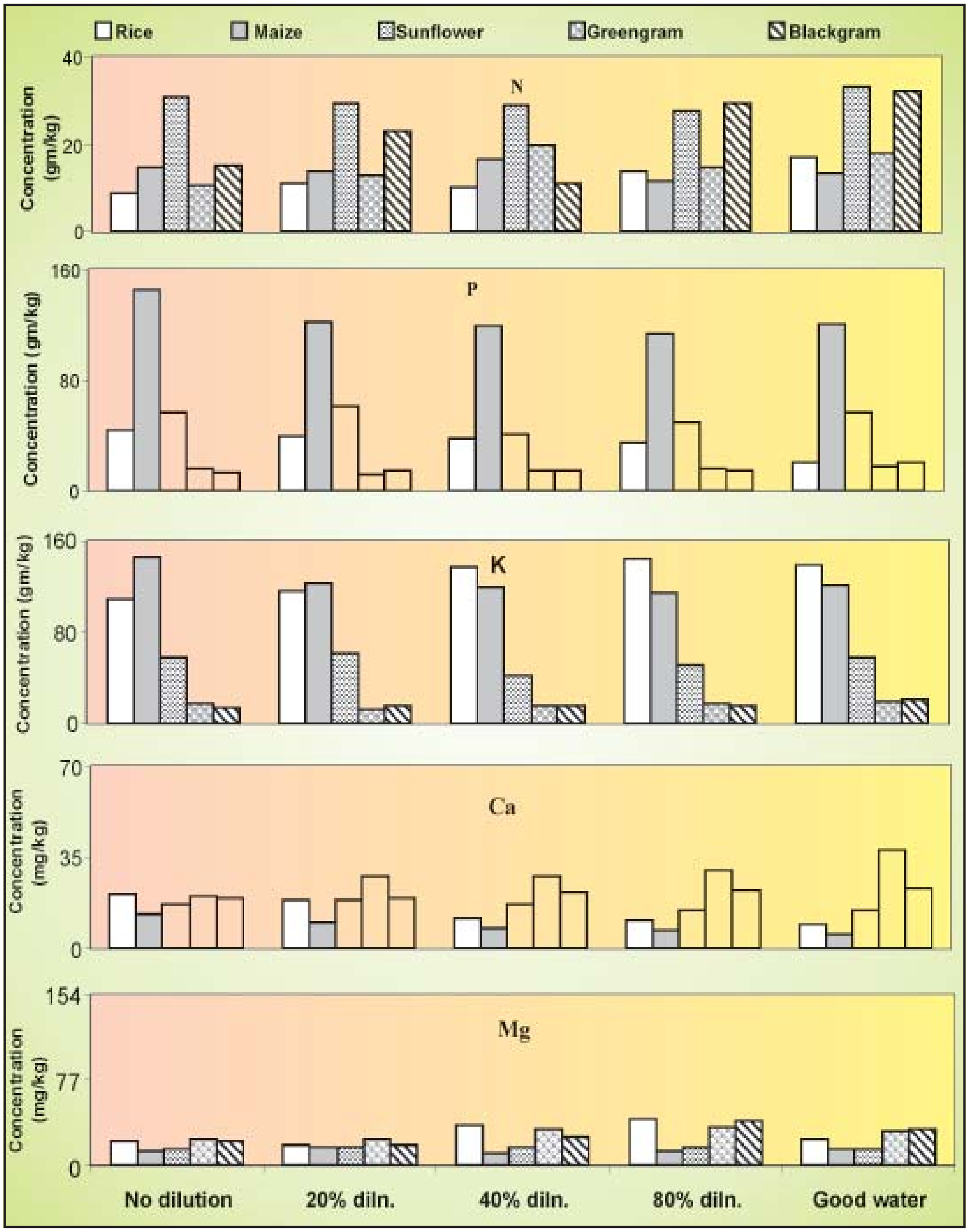
6.1 Impact of Paper mill effluent in cropping

Effluent of agro – based paper mill is in general rich in organic matter, contains different amount of suspended solids, alkali and alkaline earth metals, chloride and sulfate ions (Yong et al., 1992). Depending on nature of inputs and pulping technology practice the amount of a particular or a group of constituent/s vary. The chemical compositions of three different paper mills are presented in Table 6. In the era of fresh water shortage and uncertain distribution of rainfall reuse of the effluent for crop irrigation is a promising option.

Table 6: Important characteristics of Paper mill effluent

Parameters	Effluent from different paper mills in Orissa		
	Jagatpur	Choudar	Emami
pH	7.22	7.33	7.21
EC dS/m	0.34	0.60	1.79
Na meq/l	0.43	1.94	1.15
K meq/l	0.11	0.46	0.31
Ca meq/l	2.00	2.00	22.56
Mg meq/l	0.50	0.50	5.13
Cl^- meq/l	1.00	2.50	5.85
CO_3^{2-} meq/l	Trace	Trace	11.71
HCO_3^- meq/l	Trace	Trace	23.43
SO_4^{2-} meq/l	0.63	-	0.04
NO_3^- meq/l	10.96	6.15	4.62
F^- meq/l	-	-	3.25
B mg/l	-	-	0.68
Fe mg/l	-	-	0.64
Dissolved organic matter (mg/l)	100.00	1.00	50.00
Total dissolved solids (mg/l)	204.00	328.00	276.00
Sodium adsorption ratio (SAR) $[meq/l]^{1/2}$	0.38	1.71	0.04
Adjusted SAR (SAR_{adj})	-	-	0.15
adj R_{Na}	-	-	1.97

Note: Cd, Cr, Hg and Pb concentrations were below detectable limits



TREATMENTS

Fig 5: Variability in nutrients' response with crop types under paper mill effluent treatments.

6.1.1 Pot culture experiment

Irrigation with Emami paper mill – effluent, which was neutral, low saline and contained Na, Ca, Mg, Fe, F, B, Cl, SO_4, NO_3, CO_3 and HCO_3 ions at low to moderate concentrations at different dilutions with fresh water had improved crops' yield attributes. Dilution of >60 to ≤ 80% of effluent with fresh water (v/v) was found optimal for proper growth of blackgram and maize, >20% for greengram and d ≤ 60% for rice and sunflower grown on acidic laterite soil in pots. Crop nutrient concentration was also enhanced (Fig. 5) by 17 – 49, 24 – 90, and 52 – 112% N; 6.4 – 32, 14 – 30, and 2 – 16% K and 5.22 – 82, 0.6 – 50 and 15 – 80% Mg in rice, greengram and blackgram respectively. It was 17 – 96% N, and 27 – 44% K, in maize and 6 – 14% Mg in sunflower. A successive increase of P and Ca by 75 – 117% and 9 – 117% was prevalent in rice, and 1.2 – 20 and 18 – 137% in maize from 100 to 0% dilutions. The paper mill effluent irrigation improved N, P, K, Na, Ca and Mg contents in soil over their corresponding initial values and also over 100% dilution (i.e. only fresh water) without showing any trend with concentrations of effluent. The paper mill effluent thus holds promise to use for irrigation if diluted to a level within the acceptable limit of crops.

6.1.2 Field experiment

Experiments conducted with Emami Paper Mill – effluent, a newsprint manufacturing unit in Baleswar, producing 4500 – 5000 M^3 of effluent per day and discharging it into the nearby water stream. *In vitro* use of this effluent reduced germination rate of maize (*Zea mays*), variety DHM 103 but improved vigour index. The *in situ* experiment with Maize in a Ca deficient (4.02 mg/kg), low P (1.38 mg/kg), sandy loam non – saline soil (Aeric Haplaquepts) with effluent irrigation (through different treatments) subsequently revealed that leaf area index and plant height at knee high stage were influenced by 32 to 33% and 4 to 28% but the impact on cob length / girth / weight was not much evident (Table 7). Grain yield was also improved by 3 to 6% while other yield attributing characters viz. grain no. per plant and grain / cob weight ratio were magnified by 19 to 29% and 1.2 to 11% due to effluent irrigation over 'normal practice' as control (Table 8).

The N concentration at knee high stage was reduced to the tune of 1.23 to 2.04 times in first year, while P, K and Ca concentrations were accelerated by 1.10 to 1.47, 1.02 to 1.09 and 1.93 to 3.07 times respectively under effluent irrigation over fresh water. Similarly Ca concentration was also enhanced (1.6 to 3.81) followed by N (1.21 to 1.32) and P (1.08 to 1.11 times) in second year without manifesting any consistent trend with effluent concentration in general. Nutrients' concentration was however augmented over fresh water irrigation in the order of Mg > K P > Ca > N (Fig. 6).

Soil fertility properties were also improved to the tune of 1.18 - 1.34 fold in organic carbon, 1.22, 1.21, 1.09, and 1.8 times in humus, carbon, available P, K and N

Table 7: Response of Maize growth parameters under effluent irrigation treatments

Treatments	Plant height (cm)	Leaf area index (LAI)	Cob length (cm)	Cob girth (cm)	Cob weight (gm)	Grain weight (gm)	Stover weight (gm)
No effluent	133.66	4.36	15.43	11.77	62.53	3.85	15.2
Effluent	96.00	2.96	15.20	11.32	53.56	3.92	15.31
Effluent & water (50:50)	118.33	3.20	14.75	10.87	56.92	3.28	14.00
Effluent alternate with water	120.00	2.93	14.10	11.56	54.50	3.29	14.19
Twice effluent alternate with water	127.00	3.33	15.03	10.30	56.00	3.22	14.67
Thrice effluent alternate with water	1.81	3.97	0.21	1.14	0.63	2.33	0.04

Table 8: Effect of effluent application on yield response of Maize

Treatment	Grain weight (t/ha)	Grain no. / plant	Empty cob weight (t/ha)	Cob length (cm)	Mean diameter of cob (cm)	Grain weight / empty cob weight	Stover yield (t/ha)
No effluent	12.07	224	3.9	14.00	12.16	3.20	8.33
Effluent	12.42	212	3.25	13.15	11.05	3.20	7.49
Effluent & water (50/50)	11.92	201	3.75	13.85	12.12	2.87	7.50
Effluent alternate with water	12.77	277	2.97	13.33	11.94	3.58	7.50
Twice effluent alternate with water	11.01	241	3.43	14.05	11.93	2.98	7.50
Thrice effluent alternate with water	11.87	316	4.19	12.79	11.59	3.24	8.75

Conjunctive use of effluent and fresh water

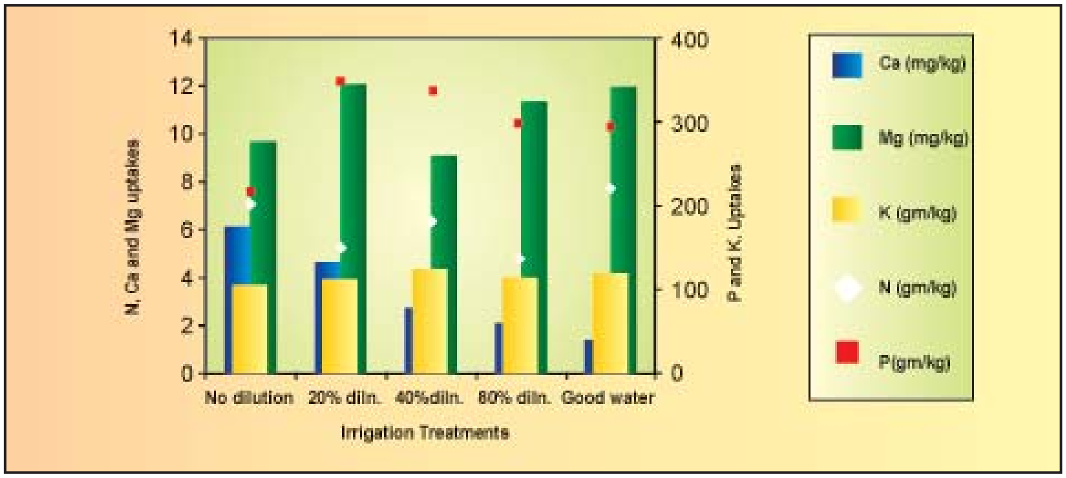


Fig 6: Effect of Paper mill effluent irrigation on nutrient uptakes in maize

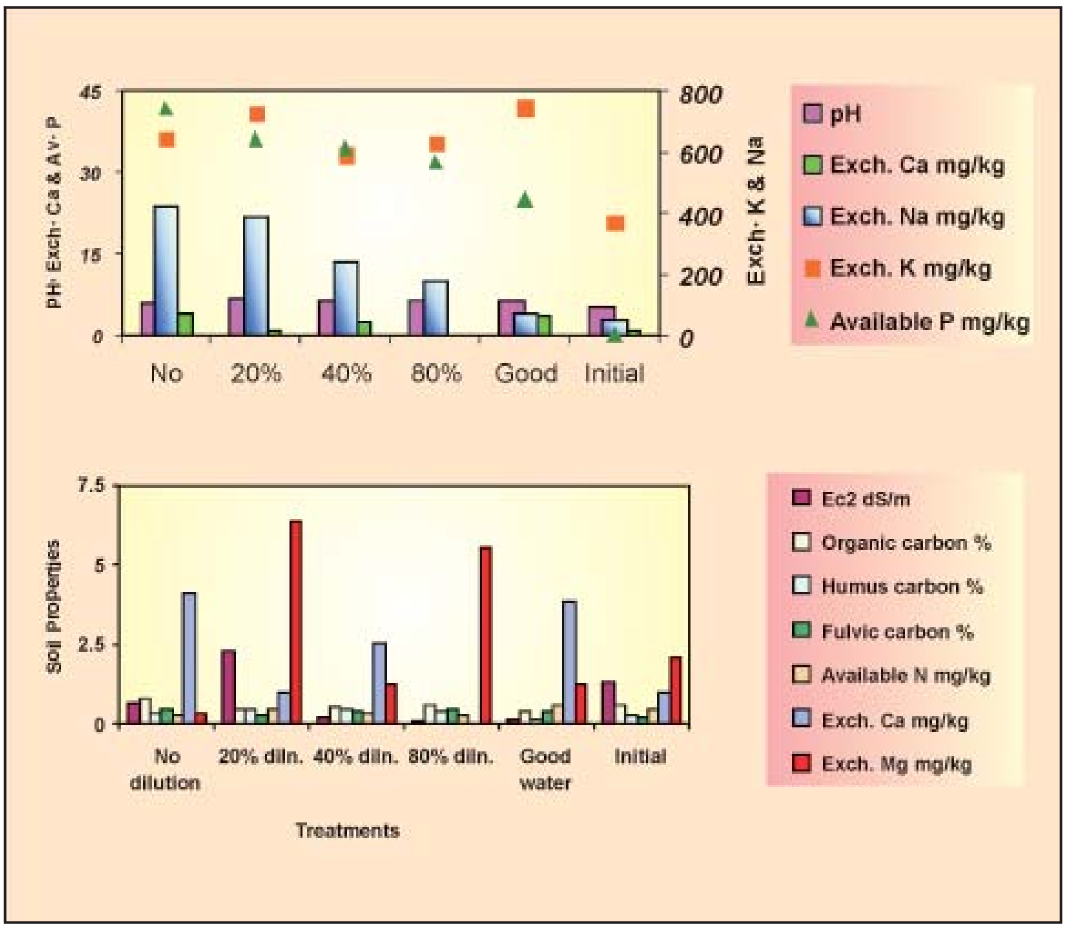


Fig 7: Impact of paper mill effluent irrigation on relevant soil properties

concentrations under effluent irrigation. The exchangeable Ca and Mg contents were modified by 1.03 to 1.04 and 1.3 to 1.74 times over fresh water irrigation as well (Fig 7). However no carry over effect of effluent irrigation was noticed in the succeeding year of study. Thus by increasing crop (maize) yield, nutrient uptakes and improving soil fertility the effluent of Emami Paper mill has been found useful and could be used for irrigation in acidic non saline soil during fresh water crisis.

6.2 Reuse of spent wash in cropping

Treated spent wash especially from cane sugar molasses distillery is an enriched source of various plant nutrients. It could alleviate soil constraints; improve environment to the level suitable for plant growth if properly managed under a specific situation. Experiment with spent wash irrigation at different dilution with fresh water in pot revealed that biomass yield of groundnut was decreased up to certain concentration level (0 to 50% dilution) and then enhanced with increasing dilution (Fig 8). The yield at 80 and 90% dilution levels was equivalent with the yield obtained under fresh water irrigation (100%). In plant tissue nutrient concentration, the P and Ca were sufficiently enhanced to the tune of 11 to 200 and 1.45 to 100% by effluent treatments over normal practice. But the increase was not consistent with dilution of effluent (Fig 8).

Initially the soil used in this experiment was moderately acidic (pH 6.3), had no salinity

Table 9: Influence of distillery effluent irrigation on important soil properties in pot experiment

Parameters	Treatments, % dilutions of effluent with water											
	0	10	20	30	40	50	60	80	90	100	Mean	SD	SEm±
pH	6.3	6.4	6.5	6.2	6.7	6.8	6.6	6.8	6.4	6.9	6.6	0.24	0.07
EC_2, dS/m	0.2	4.6	2.8	4.7	4.5	3.3	4.8	3.7	3.1	2.3	3.4	1.43	0.45
Organic carbon, %	0.35	0.58	0.52	0.67	0.55	0.47	0.55	0.52	0.47	0.33	0.50	0.10	0.03
Humic carbon, %	0.12	0.13	0.14	0.16	0.12	0.13	0.18	0.14	0.12	0.13	0.14	0.02	0.01
Fulvic carbon, %	0.10	0.17	0.13	0.17	0.14	0.17	0.12	0.12	0.23	0.13	0.15	0.04	0.01
KCl – N, mg/kg	250	410	370	470	400	350	420	370	320	220	358	77	24
Bray's P, mg/kg	24.5	44.9	25.5	31.2	28.1	28.6	26.5	20.3	27.0	34.5	29.1	6.7	2.1
†K, mg/kg	326	1504	1200	1504	1478	1451	1504.	1486	1325	869	1265	387	122
†Ca, mg/kg	90	305	209	381	305	286	343	266	286	228	270	80	25
†Mg, mg/kg	27	51	39	69	42	54	66	54	54	33	49	13.57	4.29

†1N NH_4OAc – extractable ions

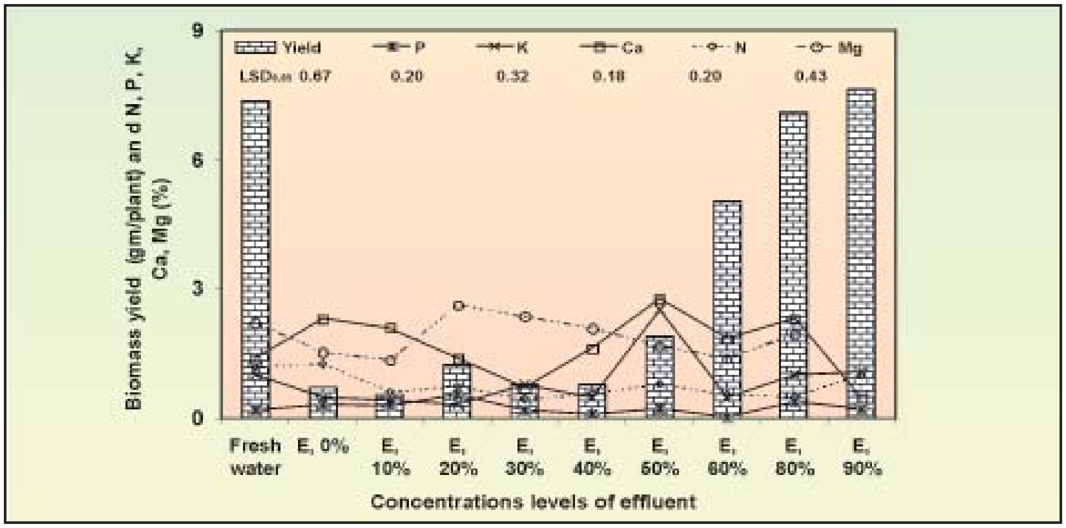


Fig 8: Yield response and nutrient concentration of groundnut under distillery efficient irrigation treatments in pot study

and contained low amount of organic carbon (<0.4%), available P, exchangeable K, Ca and Mg. But in post harvest soil, those properties were markedly improved by effluent irrigation over normal practice. The mean increase was 5, 48, 16, 53, 48, 21, 320, 221 and 90% in pH, organic, humic and fulvic acid carbon, N, P, K, Ca and Mg contents respectively (Table 9). Simultaneously the soil EC was also promoted, which significantly correlated (r value) with K (0.94, $P \geq 0.01$) and Ca (0.94, $P \geq 0.01$) and evidently dictated their preponderance in salt compositions. Apart from saving fresh water by 10 – 20% through distillery effluent irrigation at different dilutions, an accrued benefit in terms of incorporating plant nutrients in soil were also distinct from pot experiment study.

However the results of different investigations revealed that industrial effluent could also be effectively used for agricultural production. But prior to use understanding effluent potential and knowledge on its area of use are vital for mining its benefits for agriculture. The effluent reuse should not be always seen as an alternative of fresh water resource, it could also be taken as agricultural input (some effluent) for supporting crop production. Application of nutrient rich effluent would be a better practice than normal water irrigation in some location specific situations.

7. PROSPECT OF INDUSTRIAL EFFLUENT REUSE IN CROPS

Effluent water reuse is a promising option particularly during water shortage. Assessing irrigation potential and perfecting its use in particular soil type/s has been proved effective by ensuring crop return without affecting the quality of resources.

Such as near neutral, saline nature, Ca and Mg salt enriched paper mill effluent has come up as suitable and alternate irrigation source for acidic, non – saline Ca deficient soil. Irrigation with the effluent @ 5 cm per application has been found capable of to augment grain yield by 3 to 6% in Maize. Nutrients' concentration was also improved over fresh water irrigation in the order of Mg > P > Ca > K. No decline in important soil properties (pH, organic carbon, available N, P, K, exchangeable Ca, Mg) or increase of any unfavorable substance (Cd, Cr) was evident.

Again for irrigation with cane molasses based distillery effluent (post methanated) alternate with fresh water or 50/50 as effluent / fresh water ratio has been found most favorable concentration to irrigate groundnut growing in non – saline, acidic red and laterite soil. Groundnut pod / kernel yield was not affected rather substantially improved over fresh water irrigation, without sparing nutrient uptake or soil properties. However proper guidelines and management practices need to be followed for safe use of effluent water in crop production.

8. GUIDELINES FOR INDUSTRIAL EFFLUENT REUSE IN AGRICULTURE

Reuse of industrial effluent induces risk to infect soil, water and crops though imminent in agricultural perspectives. Detail guidelines are available for safe and secure use of effluent in different perspectives. However in effluent reuse practice, to abate adverse impacts of effluents, protecting soil health and crop quality the steps need to follow are:

- **Characterization of effluent**

Prior to put into practice the effluent needs to thoroughly analyzed and estimated for its constituents, which reveals the type and quality of effluent.

- **Evaluation of effluent potential by comparing its characteristics with different irrigation water quality standards**

After characterization, prioritization of effluent constituents as per their potential to cause damage is required in this process. This prioritization will help to eliminate the effluent if contain hazardous element / compounds, such as heavy metals beyond their corresponding standards at the first instance. Heavy metal causes irreversible damage on living beings. Thus the step will help to disclose effluent's ability to be used or not-used in irrigation purpose.

- **Match the effluent characteristics with relevant properties of dominant soil types**

Soils are differed by their contents and characteristics. Different soils are dominated in different regions. This could be used as an yardstick for effluent selection and improve its prospect of utilization in cropping, such as soil with acidic pH and low salinity can be used for receiving effluent of high pH and high salt content. In this way the effluent's liabilities could be conditioned and its potential can utilize for cropping. The soil based effluent reuse option could be employed if the information of soil as par availability of fresh water resources is known in various locations / regions.

- **Identification of effluent quality indicators**

For surveillance of effluent quality, testing of number of properties in regular interval is a major burden in effluent reuse program. Identification of salient properties of effluent will help to relieve the load while monitor its quality in an effective manner. Choosing of appropriate mechanism to screen effluent properties and select the properties as indicators is vital in this process

- **Check the quality of crops, soil and adjacent water resources**

All steps are mandatory for effluent reuse practice. But for continued use of same kind of effluent, monitoring of indicating properties (effluent quality indicators) and a strict vigil on soil / water / crop quality are highly required to promote its safe use in crop production.

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