

*Full Length Research Paper*

## **Application of electron beam technology in improving sewage water quality: An advance technique**

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The use of electron beam to disinfect sewage water is gaining importance. The current problem on environmental health in relation to water pollution insists for the safe disposal of sewage water. In general, sewage water comprises of heterogeneous organic based chemicals as well as pathogens. EB (electron beam) treatment of the wastewater was found to be very effective in reducing the pathogens as well as organic load. EB dose of 1.5 kGy was sufficient for complete elimination of total coli forms. The experimental results elucidated that the reduction of biological oxygen demand (BOD) (30.38 and 51.7%) in both inlet and outlet sewage samples. Similarly, reduction of chemical oxygen demand (COD) was observed (37.54 and 52.32%) both sewage samples with respect to increasing of irradiation doses (0.45 to 6 kGy). The present study demonstrated the potential of ionizing radiation for disinfection of sewage and to increase the water quality of the wastewater by decreasing BOD and COD. So, the irradiation sewage water can find its application either in agriculture for irrigation or in industry sector for cooling purpose or in both the sectors.

**Key words:** Disinfection, electron beam accelerator, organic matter, sewage water quality.

### **INTRODUCTION**

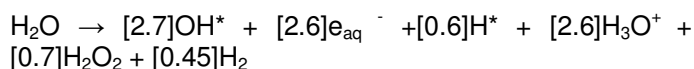
Water is an important natural source, which cover about 2/3 of earth surface. However, only 1% of the water resource is available as fresh water (that is, surface water-rivers, lakes, streams, and ground water) to satisfy human needs. In India, major cities generate large volumes of wastewater due to their inefficient water management systems. Large amount of wastewater that can be reused is letting down into either sewerage drains or nearly by aquatic resources. Furthermore, the potential for environmental pollution is greater due to high quantity of waste materials produced namely the organic matter (Shathele, 2009) and generally rich with pathogens of fecal origin, even after the treatment with conventional

methods. Few important pathogens in sewage water are bacteria (*Escherichia-coli*, *Salmonellae* sp.), viruses (e. g. Poliovirus) and Protozoans are causing various types of diseases especially of faecal oral route (Jianlong and Jiazhuo, 2007). Therefore, to protect health and the environment, new approaches should be adopted to overcome this grim situation, including remediation and the reuse of wastewater. Although, it is under scrutiny, chlorine is still widely used as chemical disinfectant for the treatment of wastewater. Treated water discharged from sewage treatment plant can be reused for irrigation. Prescribed water quality standards for recreational and other water uses, such as shellfish production, are typically based on contamination levels as indicated by number of fecal coliforms in effluents. Recently, application of ionizing irradiation, especially electron beam radiation that is generated from electron beam accelerator to treat sewage water has attracted the

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environmentalists. The chief advantage of electron beam radiation over existing chemical treatments is derived from its short wavelength and its ability to penetrate into the tissues. It was reported that ionizing radiation induces both the degradation of numerous compounds and the inactivation of microorganisms in sewage on irradiation, depending on the type of energy, dose rate and absorption (Casimiro et al., 2008). In water as well as wastewater, the principal component is water. Therefore, it would be expected that the effect of ionizing radiation might be dominated by interaction of radiation and water (Meeroff et al., 2004). As far as pure water is concerned, when exposed to ionizing radiation, the radiolysis of water can be presented as the following equation (Spink and Woods, 1990).



So if we consider pure water, each 100 eV absorbed by water will result in the generation of 2.7 radical OH\*, 2.6 e<sub>aq</sub><sup>-</sup>, 0.6 radical H\*, 2.6H<sub>3</sub>O<sup>+</sup>, 0.7 molecule of H<sub>2</sub>O<sub>2</sub> and 0.45 molecule of H<sub>2</sub> (Borrely et al., 1998).

Powerful oxidizing and reducing species (e.g., OH, e<sub>aq</sub><sup>-</sup>, H) and molecular products (e.g., H<sub>2</sub>, H<sub>2</sub>O<sub>2</sub>) are produced due to the interaction between radiation and water, so these chain reactions lead to the phenomenon as described earlier by Parker and Darby (1995) and Sommers and Glenn (2006). Therefore, the effects of Electron beam irradiation on the inactivation of microorganisms, mainly on the pathogens as well as reduction of organic load present in sewage water were investigated.

## MATERIALS AND METHODS

### Sewage water sampling and characterization

The water samples were collected from sewage water treatment plants (A&B), Mumbai (inlet area from where raw sewage is entering into the plant and outlet, that is, prior to chlorination). The samples were brought to the laboratory with necessary precautions and analysed (biological oxygen demand (BOD) chemical oxygen demand (COD) and total colony) by adopting standard procedures (APHA, 2005). All samples were analysed for same parameters after EB treatment at different doses (0.45, 0.75, 1.5, 3, 4.5 and 6 kGy) at room temperature.

### Dosimetry study

The dosimetry study was carried out by using FWT60 radio chromic films calibrated by graphite calorimeter. Graphite calorimeters with different thicknesses had been designed and fabricated for the dosimetry of 2 MeV electron beam accelerator. Absorbed dose had been measured for each of the calorimeter body having different thickness under 2 meV electron beam at ILU-6 accelerator at electron beam facility of the radiation Technology Development Division, Bhabha Atomic Research Centre, Mumbai. ILU- 6 pulse accelerator parameters during the experiment were as follows:

Energy-2 Mev, average beam current- 1.02 m, pulse repetition frequency- 10 Hz, conveyor speed ≈ 10 cm/s, pulse current 250 mA and pulse accelerator duration ≈ 500 μs.

### Microbial assay

Plate count method was used to enumerate the microbial count. The Hi-media plate count agar (M091-500G) was used for total bacterial count, Hi-Media MacConkey Agar (M081A) for coliforms and Hi-Media *Salmonella shigella* agar (M108) for total *S. shigella* was used. The wastewater samples were diluted in phosphate buffer (Hi-Media M 461) and were used on spread plate method on agar, then incubated at 37 °C until colony formation was observed.

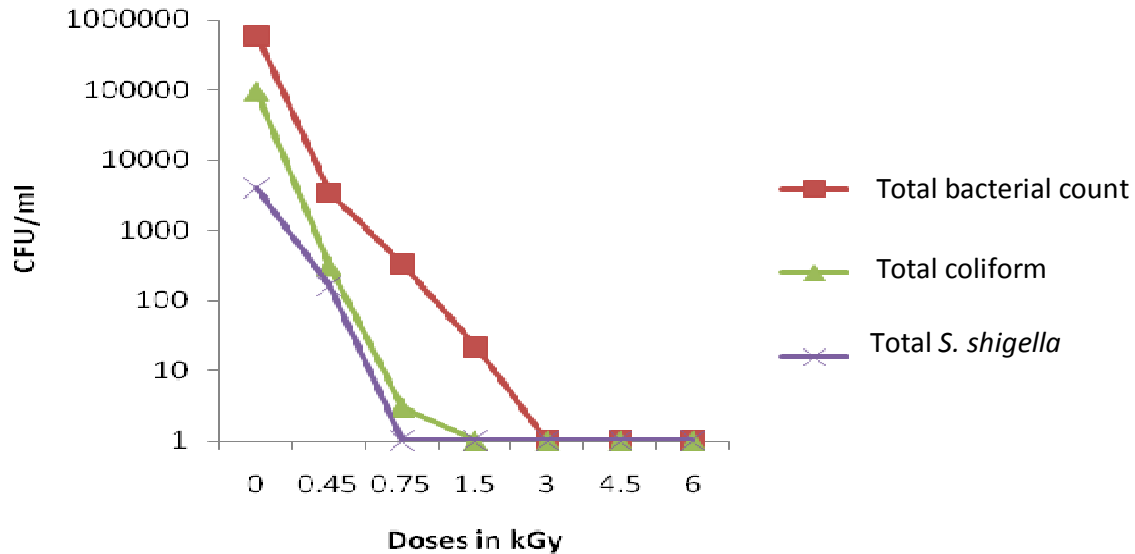
## RESULTS

The effectiveness of EB treatment was evaluated by determining total colony, BOD and COD of pre and post irradiated sewage water samples. The effect of electron beam treatment on selective parameters is summarized in Figures 1 to 8 and Table 1.

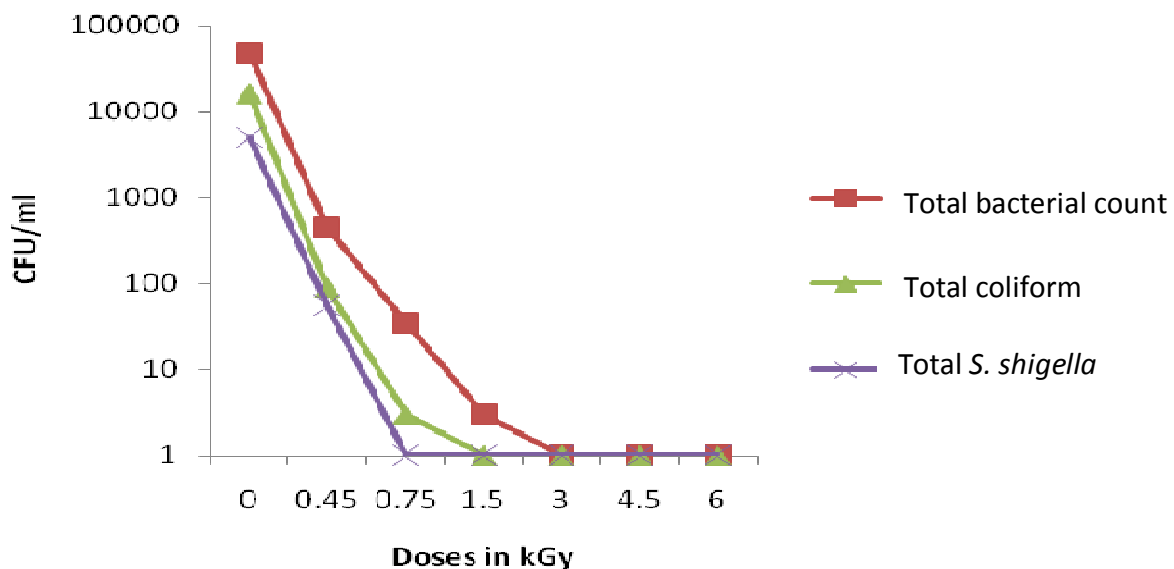
### Inactivation of microorganisms in the sewage water

Several samples were obtained from the plant to examine the inactivation of microorganisms with radiation technology. Figure 1 to 4 shows the inactivation of total and faecal coliforms (organisms per ml) in the raw inlet and unchlorinated outlet water samples. Our study observed that both total and fecal coliforms were reduced to below detection limit. The total bacterial count reduced from  $6.1 \times 10^5$  to 0 at 3.0 kGy, total coliforms count reduced from  $9.6 \times 10^4$  to 3 at 0.75 kGy and total *S. Shigella* count reduced from  $4 \times 10^3$  to 0 at 0.75 kGy in the case of treatment plant-A, inlet sewage water sample and total bacterial count reduced from  $4.8 \times 10^4$  to 0 at 3.0 kGy, total coliforms count reduced from  $1.6 \times 10^4$  to 1 at 1.5 kGy and total *S. shigella* count reduced from  $5 \times 10^3$  to 0 at 0.75 kGy (Figures 1 and 2). Similarly for inlet sample of treatment plant-B, the total bacterial count reduced from  $6.8 \times 10^5$  to 0 at 3.0 kGy, total coliforms count reduced from  $10.6 \times 10^4$  to 36 at 0.75 kGy and total *Salmonella-Shigella* count reduced from  $1.4 \times 10^4$  to 23 at 0.75 kGy and for outlet samples, total bacterial count reduced from  $5.2 \times 10^4$  to 0 at 3.0 kGy, total coliforms count reduced from  $1.9 \times 10^4$  to 1 at 1.5 kGy and total *Salmonella-Shigella* count reduced from  $5.4 \times 10^3$  to 13 at 0.75 kGy (Figures 3 and 4).

In this study, EB (electron beam) treatment was found to be very effective in reducing the bacterial count, especially total coliforms count to a safe level and the D<sub>10</sub> values of the total bacterial count, total coliforms and total *Salmonella-shigella* was found to be ≤ 0.4 kGy (Table 2). The effectiveness of gamma and EB in eliminating bacterial load was also reported by Rawat et al. (1998).



**Figure 1.** Effect of electron beam irradiation on microorganisms of sewage water (treatment plant-A, Inlet sample).



**Figure 2.** Effect of electron beam irradiation on microorganisms of sewage water (treatment plant-A, outlet before chlorination, sewage sample)

## Water quality improvement in the sewage water

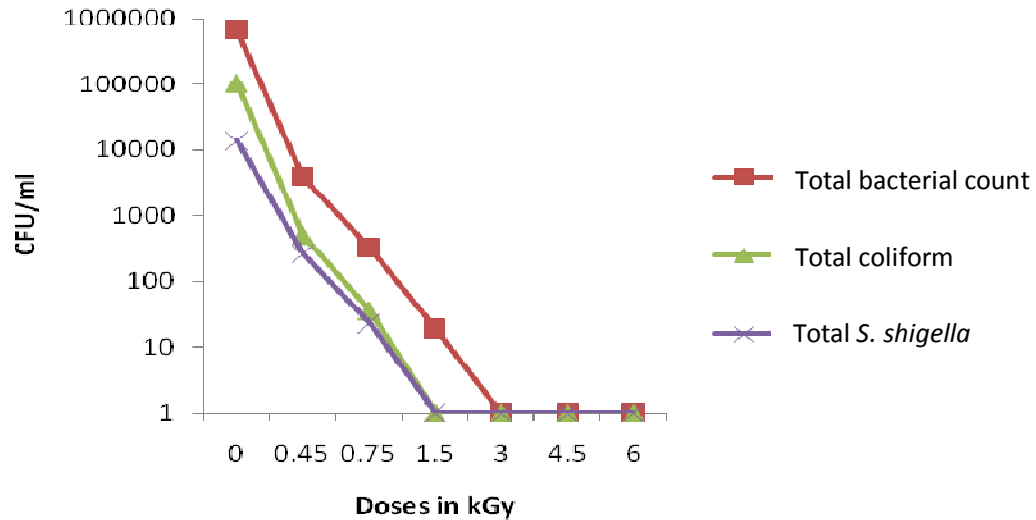
### Biological oxygen demand (BOD)

The samples were irradiated with different doses ranging from 0.45 to 6.0 kGy. The removal percentage of BOD of inlet sewage water sample was increased from 7 to 14.5 for the dose 0.45 to 6.0 kGy and for outlet water samples, the removal of BOD was up to 51.7% in the case of treatment plant-A as shown in Figures 5 and 6. Similarly for treatment plant-B, the percentage of BOD was found

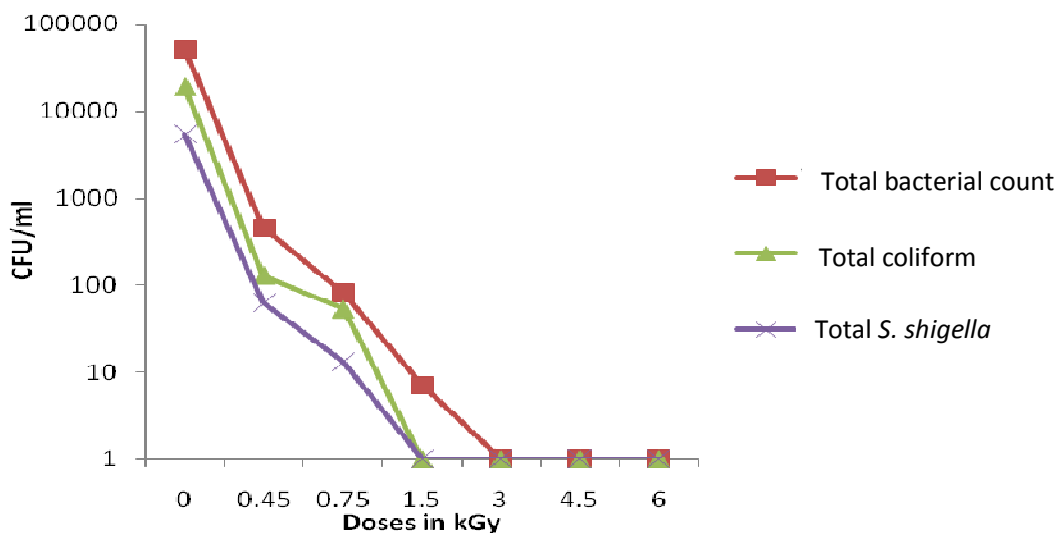
to be increased from 7.73 to 30.38 in the case of inlet sewage water sample and for outlet water sample it was up to 47.16% with the same doses as represented in Figures 7 and 8.

### Chemical oxygen demand (COD)

In the present study, it was observed that the rate of COD removal of inlet sewage water sample was increased from 13.20 to 37.54 for the dose 0.45 to 6.0 kGy and for



**Figure 3.** Effect of electron beam irradiation on microorganisms of sewage water (Treatment plant-B, inlet sample).



**Figure 4.** Effect of electron beam irradiation on microorganisms of sewage water (treatment plant-B, outlet before chlorination, sewage sample).

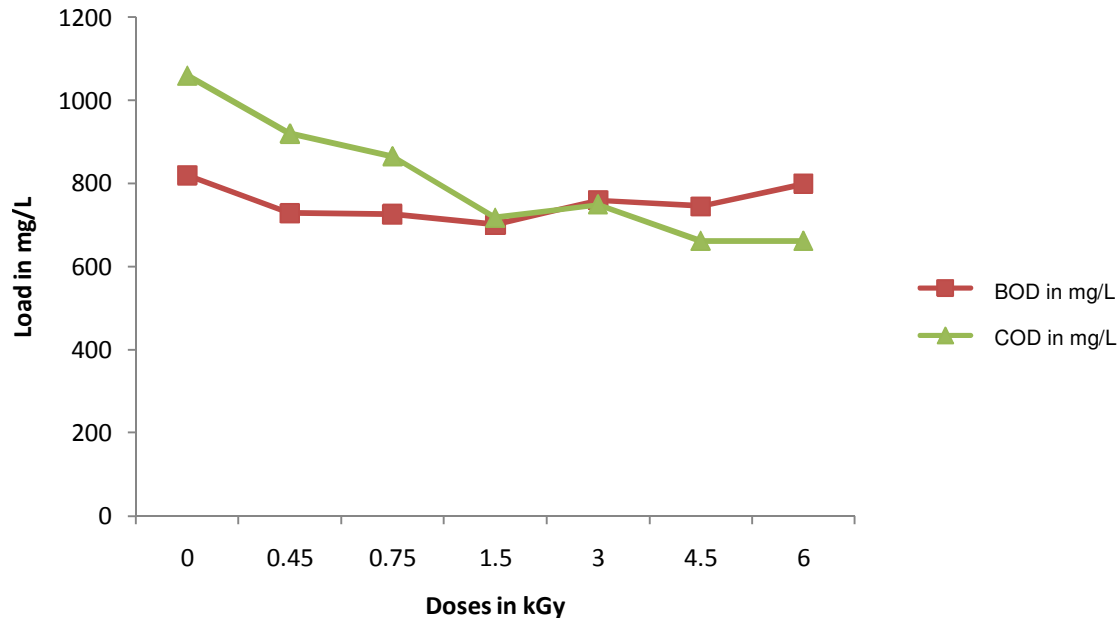
outlet water samples the removal of COD was up to 34.54% in the case of treatment plant-A as shown in Figures 5 and 6. Similarly for treatment plant-B, the removal percentage of COD increased from 12.11 to 36.05 for the dose 0.45 to 6.0 kGy in the case of inlet sewage water samples and for outlet water samples the removal of BOD is up to 52.32% with the respective doses(Figure 7 and 8).

**DISCUSSION**

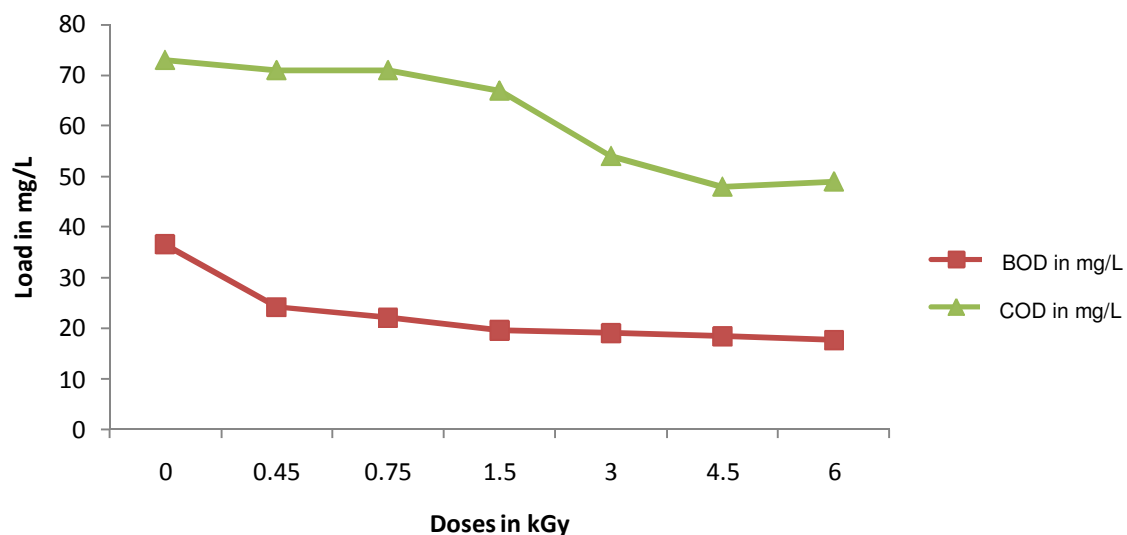
Waste water treatment aims at safe disposal of human

and industrial effluents, without danger to human health or damage to the natural environment. Irrigation with waste water is both disposal and utilisation. Some degree of treatment needs to be provided to raw municipal waste water before it can be use for agricultural and landscape irrigation, aquaculture or other uses. The required quality of effluent will depend on the proposed water uses, crops to be irrigated, soil conditions and the irrigation system (Pereira et al., 2002).

The most appropriate waste water treatment for agricultural uses is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines. Our study investigated the effects of



**Figure 5.** Effect of radiation on BOD and COD (treatment plant-A, inlet sample).



**Figure 6.** Effect of radiation on BOD and COD (treatment plant-A, outlet sample).

electron beam irradiation on the inactivation of microorganisms, mainly on the pathogens as well as reduction of organic load present in sewage water to improve the quality of sewage water.

The mechanism of killing the pathogens depends largely on the nature of the disinfectant and on the type of microorganism. In general, four mechanisms are proposed to explain the destruction or inactivation of organisms, damage to cell wall, alteration of cell permeability, changing the colloidal nature of the cell protoplasm and inactivation of critical enzyme systems

responsible for metabolic activities.

Radiation effects on microorganisms are mainly associated with the chemical changes but also depended on physical and physiological factors. Dose rate, dose distribution, radiation quality, radiation type and exposure pattern are important physical parameters and also depends on physiological factors like growth phase, sensitivity and number of microorganism etc. The action of radiation on a living organism can be divided into direct and indirect effect. If the radiation interacts with the atoms of the DNA molecule or some other cellular

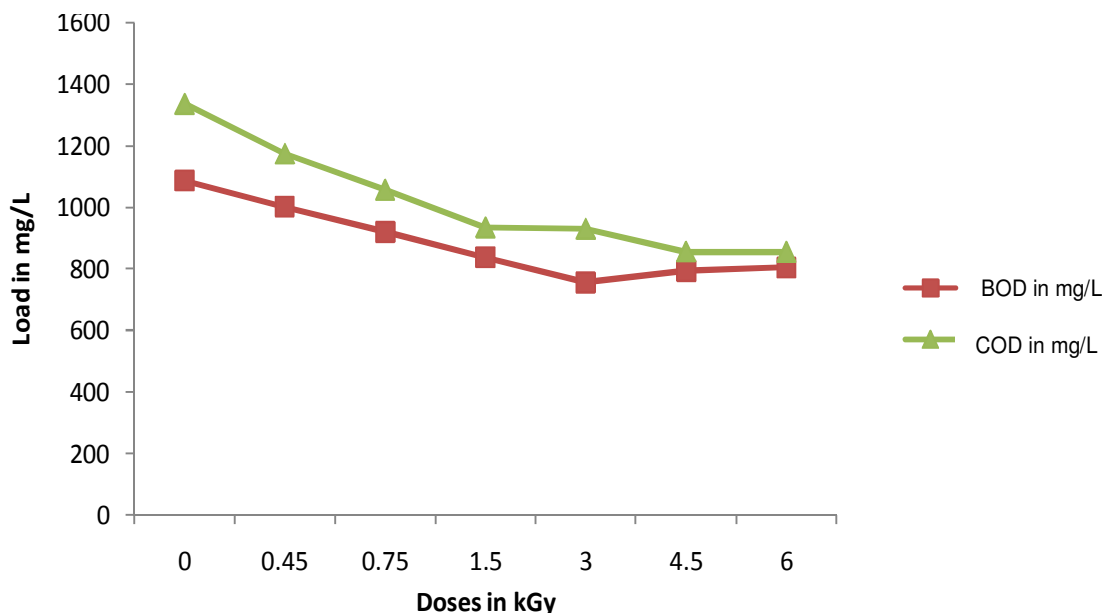


Figure 7. Effect of radiation on BOD and COD (treatment plant-B, inlet sample).

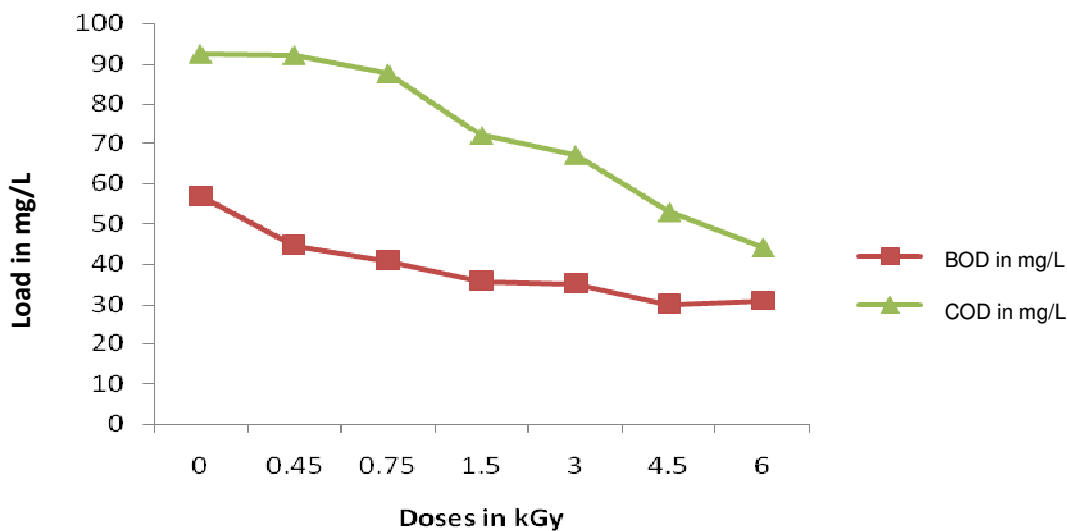


Figure 8. Effect of radiation on BOD and COD (treatment plant-B, outlet sample).

Table 1. D<sub>10</sub> Value for total bacterial count, total coliforms and total *S. shigella*.

S/N	Organisms	D <sub>10</sub> Value
1	Total bacterial count	≤ 0.4
2	Total coliforms	≤ 0.4
3	Total <i>S. shigella</i>	≤ 0.4

component critical to the survival of the cell, it is a direct effect, which will eventually affect the ability of the cell to

reproduce and survive. The formation of major radiolysis products from water and their subsequent interactions with waste particles are described as indirect effect, which is generally caused by energy deposition in the medium resulting in the formation of secondary reactants generated through free radicals production, sensitizer and secondary ionization (Borrely et al., 1998). Results obtained from present study at dose rate (3 kGy) were shown to be more efficient for the disinfection of sewage water. This excellent disinfection compared with chlorination or ozonation alone may be due to the high redox potential of the reactive radical such as hydroxyl

**Table 2.** Qualitative comparison of various treatment systems.

Factor considered	Activated sludge plant	Extended aeration activated sludge	Biological filter	Oxidation ditch	Aerated lagoon	Chlorination for disinfection	Radiation with electron beam accelerator
Organic matter removal	F	F	F	G	G	-	G
FC removal	P	F	P	F	G	G	EX
Economic factors	L	L	L	M	M	M	H

Source: Adapted from Westcot (1997) and (Pereira et al., 2002). FC, faecal coli form; EX, excellent; G-, good; F, fair; P, poor; H, high; M, medium; L, low (e. g. low demanding or low cost).

radicals produced during irradiation (Bensason et al., 1983). Biological oxygen demand and chemical oxygen demand are the major parameters used as routing surrogate tests for measuring the load of organic carbon into the water environment. In pollution abatement works, organic matter measurement provides a quick and simple method for monitoring pollution levels as well as the accumulation of non-biodegradable or refractory organic materials. The efficiency of waste water treatment plants and kinetics characteristics of biological process are usually studied through BOD and COD (Aziz and Tebbutt, 1980). The effectiveness of ionizing radiation to remove toxic organic chemicals from aqueous solutions has been already reported by Huaying (2002) and Getoff (1999). The present study revealed that the reduction percentage BOD and COD of outlet samples was more than the raw sewage samples with the same dose (6 kGy) because of other interference present in raw sewage and as per present study graphs showing after 3 kGy dose, the biodegradability was increased. It may be complex compounds are converting simple biodegradable compound for radiation dose after some extend, that is, COD is contributing BOD in study water sample (Woods, 1994) (Figure 5 to 8). Moreover, treating of sewage by combination of both EB treatment with bioflocculant (TDS will be removed), can make treated waste water fit for both industrial and agricultural purposes.

The design of waste water treatment plant is usually based on the need to reduce organic loads to limit pollution of the environment. Pathogen removal has very rarely been considered an objective but for reuse of effluents in agriculture, this must be of primary concern. Treatment to remove waste water constituents that may be toxic or harmful to crops, aquatic plants and fish is normally not economically feasible. However, the removal of toxic elements and pathogens that may affect human health need to be considered (Pereira et al., 2002). Even though our present study is costly, the EB treated sewage water can be effectively used in irrigation as well as in industries as it does not contain any pathogens and some of the physico-chemical parameters are reduced to a safer level (Table 2).

## Conclusions

A preliminary study was conducted to evaluate the effects of electron beam radiation on sewage water. Results obtained at dose rate (3 kGy) was shown to be more efficient for the disinfection of sewage water and at same dose rate showed a substantial improvement in waste water quality with an efficient decrease in organic load that lead to a better bioremediation process. On irradiation, the organic matter in sewage water was degraded via transforming from complex to simpler molecular forms that are easily metabolized by native soil microflora during irrigation. Therefore, this study stresses the advantage of the use of electron beam radiation for sewage water remediation. Similarly, at high dose rate (6 kGy), the removal percentage of organic load in sewage increased by 50% of their initial load. Moreover, our study defends that the ionizing radiation in two ways of treatment of sewage water: (A) Lower dose rate for helping bioremediation as well as disinfection during tertiary treatment process, and (B) Higher dose rate for reduction of organic load present in sewage water.

## ACKNOWLEDGMENTS

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