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Impacts of Abattoir Waste-Water Irrigation on Soil Fertility and Productivity

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Nanthi S. Bolan and Ravi Naidu

Additional information is available at the end of the chapter

1. Introduction

Water is the most precious resource that exists naturally on the planet earth; yet, global fresh water is only less than 3% and increasing population density [1] has been increasing the pressure on global fresh water resources [2]. More importantly, impacts on freshwater quality and quantity are enormous in the current era of industrialization, modernization, over exploitation, and poor resource management practices.

Increase in global population and decrease in the availability of clean water is limiting human activities, especially industries. Most industrial processes require enormous quantity of water, which almost equally discharges wastewater [3]. Wastewater emerges from both domestic and industrial sources, untreated discharges of wastewater often contains significant amount of pollutants, nutrients and pathogens [4]. Industrial processes need huge quantity of water to meet the quality of products with customer satisfaction. The major industrial sources of wastewater include canneries, milk dairies, Sugar factories, Breweries and distilleries, Beverage industry, Meat industry, Fertiliser manufacture, Pulp and paper, Tanneries and Yeast manufacture [5]. Among the industries generating high volume of wastewater, meat industries act as a major source with the increase in meat intake by people. Agriculture and allied industry consumed the largest volume of water with more than 50 % of Australia's water consumption in 2009-10 [6].

Unsafe water and sanitation practices account for more deaths worldwide from diseases than any war claims [7]. One quarter of the world's population is without safe drinking water [8]. To overcome the pressure on fresh water sources caused by the industry, sustainable alternative methods are needed which will reduce the pressure on global fresh water resources as

well as to meet the demand of water for households, industries and agriculture [9]. There is a wide range of environmental challenges facing the industrial sector globally, especially in the sustainable management of wastewater. With stringent environmental laws in most of the developed nations, industries needed to adopt the existing cost-intensive treatment methods including phytoremediation, land treatment and constructed wetlands [10, 11].

Therefore, development of a low-cost wastewater management technology is needed to treat the wastewater from various sources. Among the low-cost technologies, landfilling has been the most popular and widely followed technology for its convenience in handling and easy maintenance [12]. However, long-term discharge of effluents builds up the levels of nutrients, organic matter and heavy metals posing different kind of threat in terms of land degradation and pollution of surface and underground water resources. Hence, growing plants on the wastewater treated soils can emerge as a sustainable measure towards water resources management, which can be termed as phytoremediation. This approach is not only energy efficient and aesthetically pleasing method of remediating sites with low to moderate levels of contamination but can also be used in combining with other more conventional methods. It will provide potential solutions to reduce the cost of meat production and it will also help to protect our natural resources for the future generation. Overall fresh water consumption is reduced by adopting water efficient techniques and water reuse where water resources are scarce [13]. This book chapter aims to describe the effects of wastewater irrigation on soil fertility and productivity, assessment, mitigation, and farm nutrient budget based on waste-water driven nutrient.

2. Global wastewater scenario

Around 90 per cent of wastewater produced globally remains untreated, causing widespread water pollution. An approximate estimate of global wastewater production is about 30-70 cubic meters per person per year causing significant impacts on the natural environment [14]. Globally, meat industry wastewater act as a major source of industrial wastewater, for example in Australia, meat industry generates an average of 7225 ML /year. The concerns over con-serving water resources have led to new innovations for the sustainable management of Australia's wastewater into usable water resources. In the last 30 years, reuse of wastewater for agriculture has been increased due to the decline in fresh water sources, dry weather, heavy runoff loss, and overexploitation [15]. The sources of wastewater are illustrated in Figure 1.

2.1. Wastewater production

Global water consumption is doubling every 20 years and by the year 2025 two out of three people in the world will be living under water scarcity, especially in under developed and some developing countries [3]. Over 1.1 billion people across the globe lack access to safe drinking water and 2.4 billion to adequate sanitation. As a result, a child dies every 15 seconds from water related diseases [16, 17]. The health of a person depends on the quality and quantity of water for sustaining good health and vigorous life. Since agriculture, households and
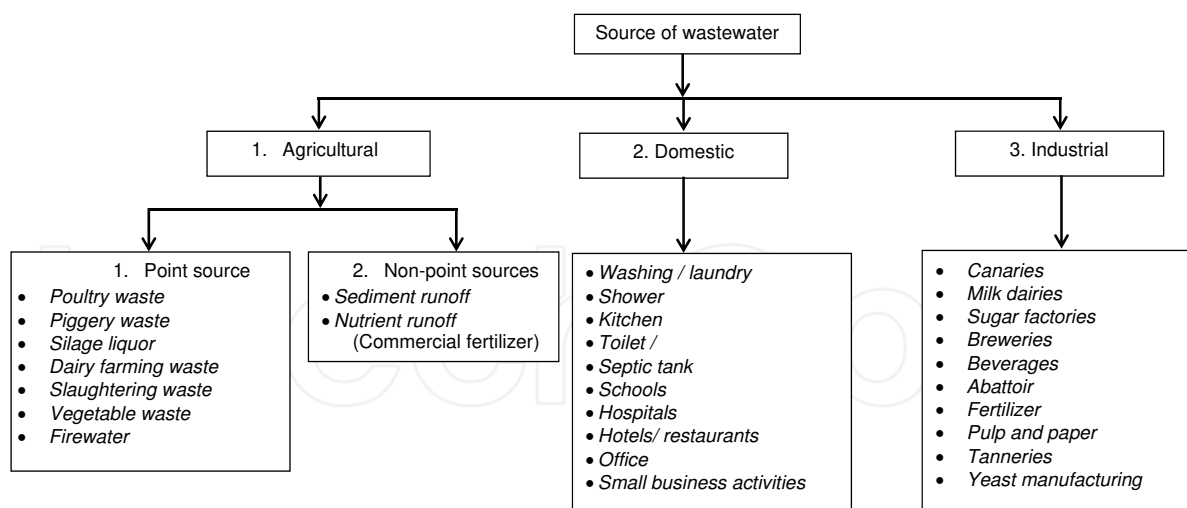
Figure 1. Sources of wastewater streams

industries are the three sectors which consume majority of water, they generate large volume of wastewater. For example, in Australia domestic wastewater aloneis being produced at 44165 litters per person per year [18], country's total of 1040.3GL/year [6].

Wastewater which has been used at least once, and has thereby been rendered unsuitable for reuse without treatment is being collected and transported through sewers [19]. Industrialization positively increased the number of industries around globe, and this proficient growth has significant impacts on the natural environment. Since, Australia is among the driest countries on the globe, having very minimal river runoff (about 1%) [20], it's necessary to re-use all the wastewater discharged to natural environment.

2.2. Characteristics of different types of wastewater

It is important to characterise wastewater before it is being re-used for many purposes. The nature of wastewater depends on the industry type and material processed. For example, the wastewater discharged from abattoir is different from winery; hence the understanding on chemical characteristics is important. Abattoir wastewater derives organic loads from different sources. Animal manure contributes significant amount of pollutants to the abattoir effluent containing N, P, and organic carbon [21]. In comparison with other wastewater sources, abattoir wastewater stream possess the highest concentration of organic load, with increased COD (8000 mg/L), proteins (70 %) and suspended solids (15-30 mg/L) [22].

Piggery effluent contains 158-1025 mg/L of N; 11-123 mg/L of P; 97-1845 mg/L of K and 103-2870 mg/L of Na with other beneficial micro nutrients [23]. According to the APL-AMIC –projects report, water usage, feed grain supply and managing nutrients in the piggery effluents are the major environmental challenges faced by Australian piggeries [24]. Piggery effluents and by-products can be used as valuable alternatives for fertiliser's agricultural production. Waste-water discharged from wineries is rich in nutrients; it contains 1-128 mg of N /L; 1-33 mg of P /L; 19-1250 mg of K /L and 18-880 mg of Na /L [23]. Organic load or waste load in the winery

wastewater increases the nutrient content (sodium and potassium) and BOD of the wastewater, which may lead to salinity and sodicity [25]. Dairy farm generates large volume wastewater with rich in nutrients especially N and P. Dairy farm wastewater comprises of urine, faeces, chemicals from cleaning, and solid waste (cow dung). This contributes 15-200 mg of N /L; 11-160 mg of P /L; 11-160 mg of K /L [26]. Typical characteristics and nutritional composition of different agricultural industries wastewater is shown in Table-1.

Constituents	Domestic	Textile	Abattoirs	Piggery	Dairy effluent	Olive mill	Winery
SS (mg L^{-1})	350	245	2000	447	28-1900	2.8-126	60-2000
TDS (mg L^{-1})	850	1130	3500	3100-8600	138-8500		500-2200
K (mg L^{-1})			100-400	97-1845	11-160	17100	19-1250
Na (mg L^{-1})			20-150	623 (103-2870)	60-807	400	18-880
N (mg L^{-1})	50- 70		100-150	854 (158-1025)	15-200	0.09-3.2	1-128
pH		10.2	7.3	7.5-8	5.6-8	4.2-7	4-10
P (mg L^{-1})	20	3.4	100-400	109 (11-123)	11-160	1.1	1-33
BOD5 (mg L^{-1})	300	227	1300-7500	40	320-1750	1.5-100	
COD (mg L^{-1})	240-440	2120	100-250		1120-3360	6.4-162	
TOC (mg L^{-1})		2.5			201-6664		
Oil & Grease (mg L^{-1})	150		100-1000		68-240	2.26	
References	Huang et al., 2010. [60]	Yusuff. 2004. [61]	Mittal. 2004. Damien Batstone., 2012. [31,62]	EPA-SA., 2009. [23]	EPA-SA., 2009. Marimoli et al., 2011. [23,26].	Anastasiou, 2011. [63]	EPA-SA., 2009. [23]

SS – Suspended solids; TDS – Total dissolved solids; BOD – Biological oxygen demand; COD – Chemical oxygen demand; TOC – Total organic carbon

Table 1. Characteristics and constitutes of wastewater from selected sources

2.3. Wastewater disposal and treatment

Treatment of wastewater, before reuse is most important to avoid the excess load of contaminants such as solids, organic matter, nutrients and pathogens [27]. For example, untreated abattoir wastewater is unsuitable for reuse or discharge into receiving environment. It will cause serious environmental hazards in the receiving environment such as eutrophication, land degradation, nutrient leaching, ground water contamination, greenhouse gas emission and effects on ecosystem value; hence proper reduction in pollutant levels in the prior stage is essential. The various environmental impacts of abattoir wastewater disposal methods are described in the table 2.

Disposal methods	Impacts
Evaporated pond	• Odour emission • Toxicants • Pathogens (disease causing agents) • Organics and inorganics loads
Irrigation -landscape -agriculture	• Odour • Soil contaminants • Persistent of soil pollution in soil • Potential for carrying heavy metals to food chain • Bioconcentration, Bioaccumulation, Biomagnification
River Steams lakes	• High load of organic and inorganic pollutants • High load of BOD • Pathogenic organism • Unsuitable for irrigation • Odour • Eutrophication • Death of fishes • Loss of biodiversity / decrease ecosystem value
Coastal / ocean	• Loss of fish breeding • Odour • High load of organic and inorganic pollutants • Climate change • Global warming
Infiltration -Natural -Artificial	• Ground water contamination • Loss of ground water quality • Aquifer clogging • Long term impacts in the flora and fauna.

Table 2. Wastewater disposal methods and their impacts

Abattoir wastewater must be treated before it reaches the receiving environments, to maintain minimum pollutant standards [28]. Effective abattoir wastewater treatment methods should remove the pollutants, nutrients, organic load, fat, oil crease, blood and pathogens from the wastewater to ensure the low level of toxicants in the final discharge effluent [29]. Abattoir wastewater treatment involves various methods to treat the meat industry effluents and to retain the bio-wealth of an ecosystem.

There are three major types of treatment technologies (primary, secondary, tertiary) that can be used to treat the abattoir wastewater (Figure 2). A typical abattoir wastewater treatment plant should have three kinds of storage system or pond to reuse the treated wastewater into irrigating agricultural crops, the first one is anaerobic pond, followed by aerobic /facultative ponds then a polishing / irrigation pond [29]. Each wastewater treatment technique is evalu-

ated in the form of its merits and demerits by economic feasibility, technical availability, and socio–cultural acceptability. This kind of evaluation is very important to assume the waste-water recycling method to current and future.
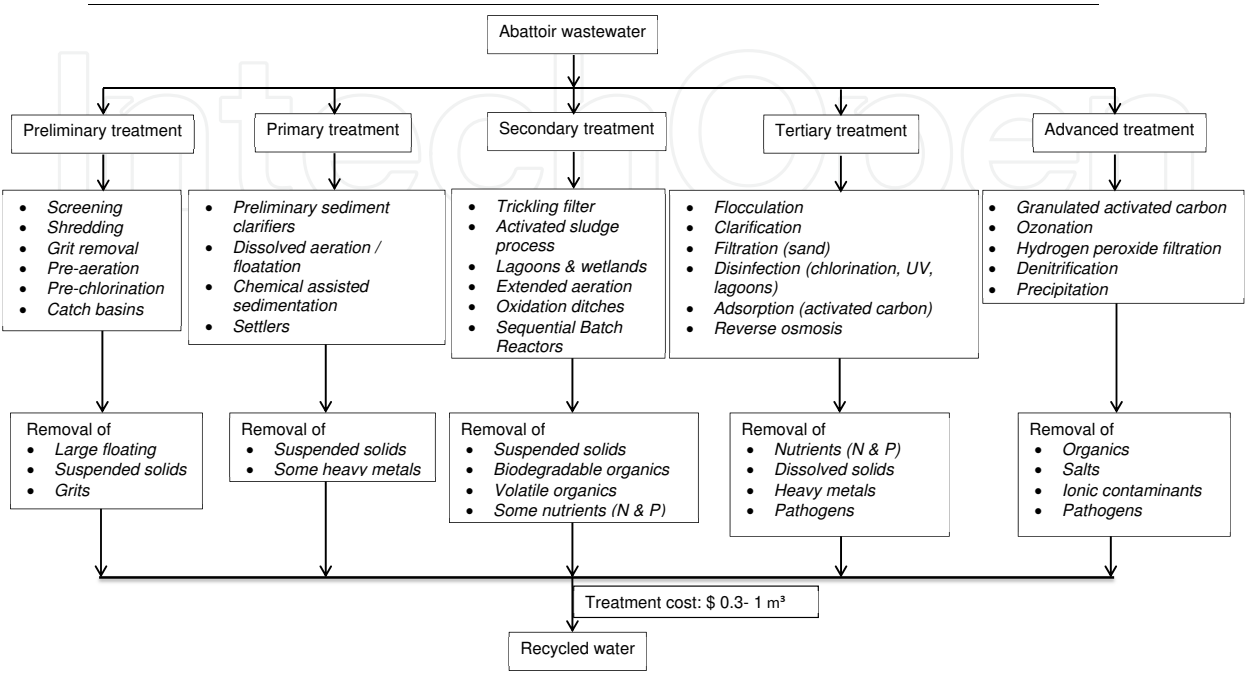

Figure 2. Wastewater treatment methods

Pre-treatments include screening, catch basins, floatation, equalization, and settlers. A primary treatment includes screening, dissolved air flotation (DAF) and flow equalisation [30]. Pre-treatments are processes that remove gross solids; coarse suspended floating matter and primary treatments remove readily settleable solids, most commonly by sedimentation [31]. Pre-treatment methods can be used to minimise the organic load and BOD in the wastewater. Pre-treatment methods such as screening and sedimentation helps to reduce 60% of solids and 25-35 % of BOD load from wastewater [32]. Anaerobic process includes lagoons, anaerobic contact anaerobic filter, anaerobic sequencing batch reactor (ASBR), up-flow anaerobic sludge blanket (UASB). An aerobic system includes aerated lagoons, activated sludge process, oxidation ditches, sequencing batch reactors and trickling filters. The advantage of lagoons in the wastewater treatments is high efficiency in organic material (BOD5) removal, at the same time very poor in N and P removal [33].

The pollutants that remain after primary treatments can be removed by secondary treatment methods, including fine suspended solids, colloidal and dissolved organic matter by biological / chemical treatment by aerobic or anaerobic process. Anaerobic contact reactors (ACR) are the best treatment system that reduces the BOD levels by 90% and volatile solids removal by 41-67 %. The issue with anaerobic reactors is odour generation, which can be minimised by installing synthetic floating covers on the lagoons, to avoid odour as well as to trap biogas [34]. Temperature is one of the limiting factors of anaerobic lagoon, which determine the efficiency

of lagoons and most anaerobic lagoons are more effective when temperature is above 21ºC [35]. In many countries aerobic-anaerobic stabilisation ponds are most widely used to treat abattoir wastewater and its efficiency varies from place to place, for example, in New Zealand, the ponds remove less than 35 % of N [36].

Anaerobic lagoons can be an effective wastewater treatment technology, for its ability to reduce BOD 97%, COD 95% and SS 96 % [37]. Hence, it is considered as the best available treatment technology for the slaughterhouse wastewater, since meat industry wastewater is rich in organic pollutants [38,39]. This method is most popular in countries like USA and Australia mainly because they have suitable climate and large land availability to adopt anaerobic lagoons in wastewater treatment [34]. In meat industry wastewater, N and P can be removed biologically using granular sludge method, with a removal efficiency of TN-86 %, TP-74 % and COD-68 % [40].

Nutrient removal is an important treatment process in slaughterhouse wastewater treatment and is the final or tertiary stage treatment. Nutrients such as N and P are introduced to the receiving area if industries fail to adopt nutrients removal before discharge into sites. Majority of the industries reuse their wastewater for various purposes especially irrigating the crops/ lawn. Environmental factors of an effective treatment system are shown in figure 3.This helps to maintain soil fertility, productivity and sustainability whereas discharge into river, ocean need an appropriate nutrient removal techniques to reduce the nutrients concentrations to minimum acceptable level. Advanced treatment processes (Granulated sludge, Sequencing batch reactors, integrated aerobic-anaerobic film reactor, Aerobic-anaerobic stabilisation pond, Anaerobic treatment methods) helps to reduce the concentration of nutrients in the effluent, most essentially N and P. Eco toxicity level of the wastewater quality standards and their usage are summarised in the Table 3.

Parameter	Irrigation	Sewer large city	Sewer small town	Coastal surface water	Inland surface water	Reuse non potable (a)
BOD (mg L^{-1})	Site specific 4000		600	10	10	100
pH		6.5-8.5	6.0-10.0	7.0-9.0	5.0-9.0	6.5-8.5	5.5-8.0
TDS (mg L^{-1})	1000	NA	NA	NA	500	1000
Coliforms (Org 100 mL^{-1})	1000	No limit	No limit	1000	200	1000
TN (mg L^{-1})	Site specific 500		100	15	10	150

(Source: MLA-RPDA-1998); a) Typical for non-potable reuse.

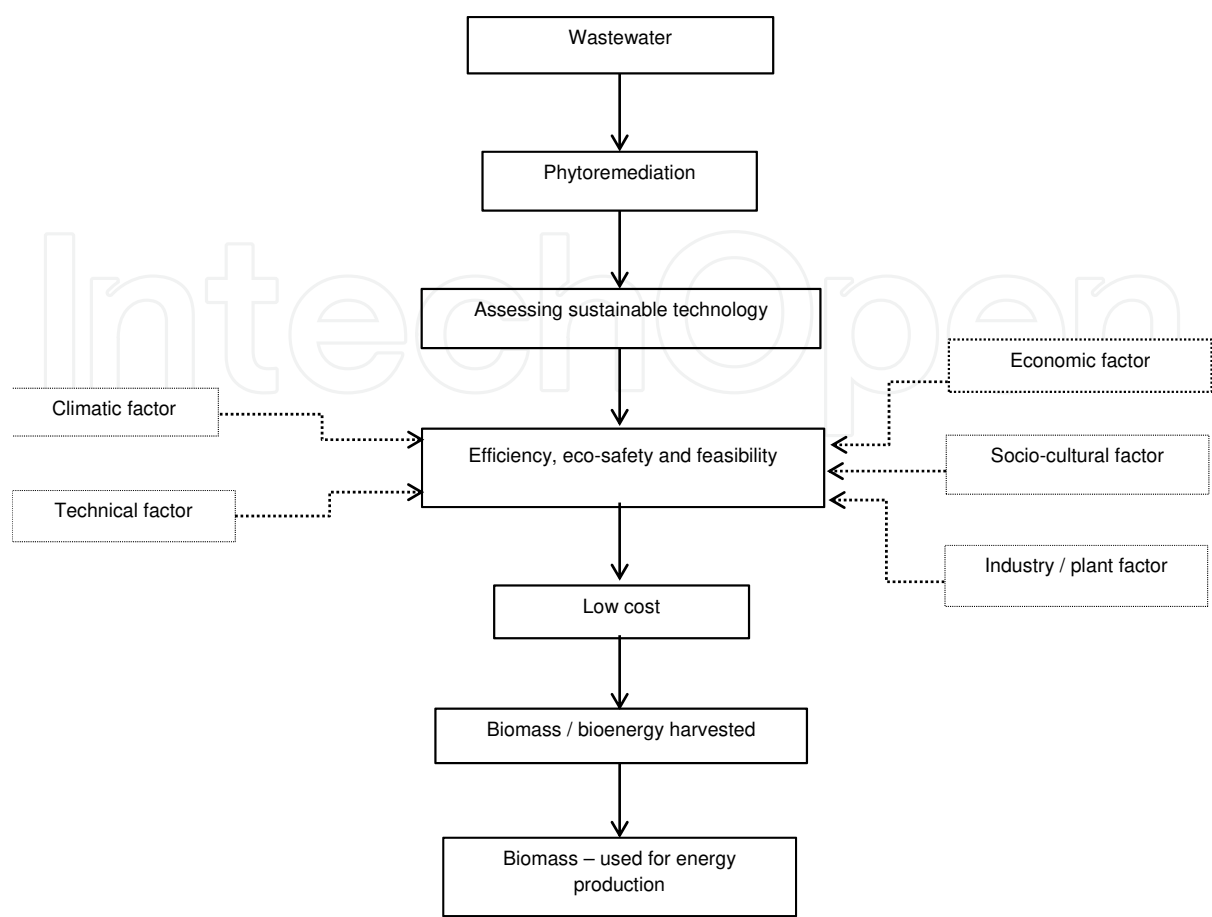**Table 3.** Abattoir wastewater disposal quality

Figure 3. Factor influencing wastewater management plan involving phytoremediation

3. Effect of wastewater irrigation on environment and soil

The impacts of the abattoir wastewater on the natural environment can be broadly classified into three categories viz, health and social impacts, economic impacts and ecological impacts.

3.1. Health and social impacts,

3.1.1. Air pollution

Air related problems in abattoir waste water can be caused by dust, flies and odour which will have strong impacts on the adjacent areas. Abattoirs are generally known as "dirty" due to various pollutants or dust generation activities such as rendering and slaughtering [41].

3.1.2. Disease causing pathogens

Wastewater carries diverse microbes that can contaminate the water sources [42], leading to the spread of pathogens from one place another [31]. This may lead to a wide range of diseases

such as cholera, typhoid, and dysentery [43].Wastewater discharges from slaughterhouse without proper disinfection, leads to occurrence of meat based infections due to the high populations of *E. coli* and *Salmonella sp.* [44].

3.1.3. Odour and noise nuisances

Odour is a most common issue associated with abattoir wastewater [45]. Odour is a problem, if abattoir wastewater is not treated completely to control the biological oxygen demand (BOD), which may result in the anaerobic activities [34,46]. The majority of the meat industry sites reported that emitting nuisance odour and noise is a serious issue for the local community. The most common sources of odour emissions from the meat industries are:

• Wastewater storage pond & wastewater treatment areas.

• Wastewater irrigation sites /land

• Rendering and by-products plants

• Truck deliveries for rendering

• Animal wastes such as urine and faeces

The most common sources of noise pollution are:

• Boiler steam blowdown

• Bellowing cattle

3.1.4. Aesthetic amenity

Aesthetic amenity / loss of aesthetic value can be observed in majority of the industrial zones and disposal sites. It has significant impact on the loss of land value and aesthetics, ultimately reducing further urban development. Abattoir wastewater has disruption of recreational use of the waterways due to pollution, for example, odour nuisance and aesthetic amenity [46].

3.2. Economic impacts

3.2.1. High cost

Most abattoir industries are established away from the urban areas due to the cost of land and high capital requirement for waste and wastewater disposal [28]. Abattoir wastewater significantly increases the cost for wastewater treatment, disposal and reclamation of contaminated sites [47].

Estimated cost disposal methods

$1.95/kL discharge into sewer

$1.55/kL discharged into waterways

$0.60/kL discharged into land

Abattoir wastewater treatment and disposal requires high cost. For example, in Canada about Can\$ 0.70-1.60 / m^3 and in the United States, about is US, \$20 / 0.159 m^3 or US \$30-40 / m^3 are being paid by the meat processing industry for the disposal of beef slaughter residues [38]. Most small and medium abattoirs do not have the tertiary and advance treatment facilities, due to high capital involved in these methods [31, 38].

3.2.2. Loss of land value:

Disposal of poorly treated and untreated wastewater in a land will reduce the value of land both by cost and productivity. Abattoir wastewater is mostly treated mechanically and also biological treatment system in ponds. Any leakage of effluents from ponds may result in serious ground water pollution due to infiltration of nitrate and phosphate [46]. Since abattoir wastewater discharges carry significant amount of pollutants their disposal to land need high investment, which may result in the loss of land value [34].

3.3. Ecological impacts

3.3.1. Algal blooms or microbial blooms or toxic algae

Disposal of abattoir wastewater without proper treatment leads to the deterioration of the water quality. Wastewater with its rich nutrient content can cause profuse growth of algae (algal blooms) that kills fish and other aquatic flora and fauna [34]. Abattoir wastewater with its rich nutrient content (nitrate and phosphate) from animal manure and various processes directly influences the growth of algae in the aquatic ecosystem. Prolific growth of algae is called as algal blooms, posing a direct threat to ecosystem.

3.3.2. Soil contamination:

Soil contamination is caused by discharges of poorly treated wastewater, which may contain heavy metals, organic compounds, inorganic compounds, soluble salts and pathogens. In the absence of effective management strategies, pollutants find pathways to enter groundwater and food chain causing serious threats to natural environment and human beings. Wastewater can be used for irrigating the crops, but the concentration of pollutants and nutrients load above threshold level will cause serious soil problems including soil salinity [48]. Inappropriate nutrient management in the wastewater system leads to deposition of excess amount of nutrients in the disposal sites and further causes potential effect on soil fertility and productivity. Continuous discharge of abattoir effluents over the same site results in soil contamination, thereby affecting soil biodiversity and productivity. Consequently, productive land and clean water resources are becoming scarce due to the following issues [29]:

- Wastewater from stabilisation pond, effluent evaporation-Increased salinity

- Surfactants derived from equipment cleaning-Increased alkalinity

- Organic / solids / manure transfer to wastewater and wetlands-Increased turbidity

Continuous disposal of effluent system can create a chance for ground water contamination due to nitrate leaching, and many other direct and indirect impacts can also occur [33]. Universally, land contamination is caused by industrial, mining, domestic and municipal wastes, and in Australia industries and mining are the two major sectors of soil contamination.

3.3.3. Loss of biodiversity

Discharge of untreated abattoir wastewater can cause serious threats in the receiving environments, altering the micro and macro environment of the receiving lands. The disposed nutrients and other pollutants can cause spatial and temporal heterogeneity in benthic populations and also preponderance of organisms such as oligochaetes and diptera which can also affect human beings [49].

Abattoir wastewater discharged into river can greatly impact the species diversity and development of aquatic organisms. The presence of high BOD will heavily impact on spatial and temporal heterogeneity of macro invertebrates [49]. Bioaccumulation and biomagnification of contaminants in in fishes present in abattoir effluent discharged aquatic ecosystems can affect a whole food cycle or food web and pose serious threats to the native flora and fauna [46].

3.3.4. Sources of heavy metals

Untreated wastewater discharged in landfill sites carry heavy metals which can affect the soil properties. Abattoir wastewater acts as a source of major nutrients (N and P) and micronutrients such as calcium, sodium, magnesium, sulphur and iron and trace amount of heavy metals such as cadmium, cobalt, nickel, copper and chromium [38].

3.3.5. Climate change and global warming

Meat production is a considerable source of global greenhouse gases emission (GHG), emitting methane, nitrous oxide and carbon dioxide through various stages. Livestock farming is one of the main activities responsible for GHGs emission around the globe [50]. GHGs are emitted by direct energy consumption and indirectly by feedstock production, herding, movement of animals, product transport, slaughtering, cleaning, and dressing the animal product, waste and wastewater.

Meat consumption will be high in 2020 and more consumption growth projected by 2050; predominantly in Asia and Pacific [44]. In the recent years, meat production and consumption has been increasing considerably, and predicted to peak in 2020. Global per capita meat consumption is projected to increase from 32.9 kg /rwt 2011 to 35.4 kg /rwt in 2020 [44]. A recent study at European Union states that ruminants (cows, sheep and goats) have the highest carbon footprint [50]. Total net GHGs emission of EU livestock production was estimated at 661mt of carbon dioxide equivalent (CO_2-eq) which is about 9-13 % of total GHGs emission for the EU agricultural sector; of those 23% methane, 24% nitrous oxide, 21% CO_2 (Energy use), 29% CO_2 (land use).

A considerable amount of GHGs emitted by the global animal industry, which is more than all the cars in the world together and large part of that 18 % nitrous oxide and methane

emissions; both of these gases have a far more powerful greenhouse gas effect than carbon dioxide [51]. Livestock sector accounts for 5-50% of total contribution, but it may vary from place to place [52]. The overall contribution consists of pigs-0.4%, sheep-3.4%, cattle-2.7%, and beef cattle-11.2%, which on an average emits 554kg CO_2-e/tonne hot standard carcass weight [47].

4. Nutrient management in wastewater irrigated soils

4.1. Wastewater driven nutrients

Large quantities of water are used in meat industry to wash the carcasses of the slaughtered animals and to clean the equipment's in abattoirs. The wastewater generated during these processes contain high organic loads, fat contents and concentrations of N, P and Na. Majority of the wastewater undergo primary and secondary treatments before being released into the environment. The discharged effluents can be used for irrigation as it contains free source of nutrients which potentially boosts production and also reduces fertilizer inputs. Nevertheless, proper N management is needed for this purpose to minimise possible groundwater contamination. Other environmental concerns include the increase in dissolved salts causing soil salinity or Sodicity and accumulation of P in soil. Phytoremediation can be a viable cost effective remediation technique to effectively manage nutrients in soil and prevent the water resources from contamination. By cultivating suitable plant species in the wastewater irrigated land, excess nutrients can be phytoextracted by the plants for growth. In the process, a large amount of biomass can be produced for energy generation or as a feed source for grazing animals.

4.2. Nutrient cycling in wastewater irrigated soils

Understanding of nutrient cycling in a wastewater irrigated ecosystem is necessary to avoid nutrient loss to the environment. Nitrogen cycle: The wastewater from slaughtering house contains nitrogen in organic forms; this is converted to ammonia by ammonification (NH^{4+}). This process is enhanced by bacteria in anaerobic conditions. Ammonia further oxidised in to nitrite and nitrate by nitrification process with the help of nitrifying bacteria. At the end, nitrate converted into nitrogen gas by denitrification activity in the presence of facultative microorganisms. This is the typical N cycle in an abattoir wastewater irrigated ecosystem. Similarly, (Phosphorus cycle) P occurs as both organic and inorganic (phosphate) forms in the wastewater discharged from abattoir. With over 80 % of P occurring in the organic form, plant growth depends on the conversion of organic P in to inorganic forms. In general, P cycle in wastewater irrigated soils is most complicated as compared to N due the phosphate precipitation or accumulation.

4.3. Nutrient budgeting

Nutrient budget is an accounting approach combining the cumulative effects of nutrient inputs, uptake and deposited, which can help manage nutrients by identifying production

goals and opportunities for improvements in nutrient use efficiency, and thus reduce the risk of off-farm nutrient impacts [53]. Nutrient budgeting for a wastewater treated ecosystem is more important than a farm nutrient budget. Wastewater from the treatment pond (open-pond treatment) can be used as irrigation water for fodder crops grown in the land treatment site. Abattoir wastewater typically contains a high concentration of nutrients, such as N 250 mg/L and P 30 mg/L. Annual nutrient loading used for the mass balance was calculated with the following equation.

$$\text{Nutrient uptake=nutrient requirement per kg of biomass* total biomass produced}$$

$$\text{Nutrient input=nutrient concentration/L * Total amount of irrigation}$$

The nutrient budgeting helps to minimising environmental impacts such as nutrient loss to atmosphere, leaching and overdose and efficient nutrient management for a sustainable production. Abattoir wastewater irrigation considerably increased the total dry matter yield, and nutrient uptake in soils. Dry matter production and nutrient uptake were proportional response to the rate of irrigation applied. Hence, an effective recapture all the nutrients that are discharged from agricultural industries is possible, thereby helps to meet a significant proportion of this requirement. Farm nutrient budget can be calculated using information obtained from nutrient input or wastewater irrigation rate-plant uptake – and soil test. These are the essential tools to calculate the effective nutrient budget to avoid nutrient loss to environment.

4.4. Plant productivity in wastewater irrigated soils

Abattoir wastewater irrigation considerably increases nutrient uptake in soils and the resultant total dry matter yield. Sparkling *et al* [54] noticed that wastewater irrigation significantly increases the annual and total herbage production and by up taking high N and P from soils. Similar results obtained by [55] concluded that wastewater irrigation has positive impacts on plant growth and development (crop height).

4.5. Case study

A recent study on nutrient budget of an abattoir wastewater irrigated soil showed the effect of long term abattoir wastewater irrigation on soil fertility (Figure 4). However, growing suitable plants for fodder production and bioenergy generation can help the industry to get additional benefits. The study site covers 32 hectare (16 ha currently irrigated), and receives annually about 216 megalitre (ML) of abattoir wastewater. This wastewater contains 250 mg/L of N and 30 mg/L of P. The land treatment site has received a total of 2025kgN/ha, 405kg P/ha and 1350kg K/ha plus trace elements. In overall, this site was loaded with 32.4t N, 6.4 P and 21.6t of K every year. Dry matter production and nutrient uptake were proportional to the rate of irrigation applied. The rate of application at the land treatment site was 216 megalitre (ML)/year and the total dry matter production was 110t in 2012. A total of 6t N, 1.3t P and 4.7t K respectively, was removed by herbage as nutrients uptake each year. This represents approximately 10% of that total applied.
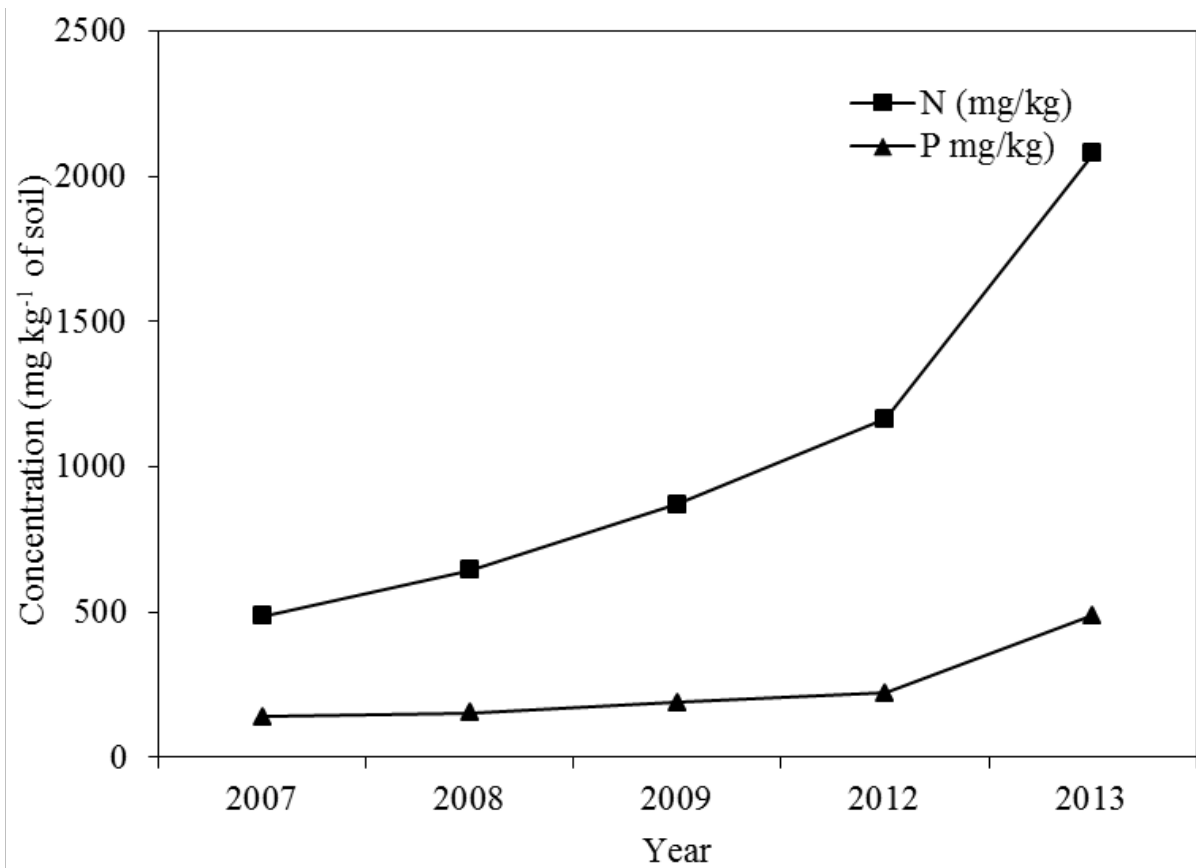
Figure 4. Effect of long-term abattoir wastewater irrigation on soil fertility

5. Sustainability concepts

It is most essential that industries need to adopt various best practices / low cost technologies to reduce their water use and cost [34]. Irrigation of wastewater is a potential low-cost approach of wastewater management and can act as a good source of nutrients for infertile soil [34]. Australia, with several meat based industries need to manage the animal wastes and effluents with low cost technology [4]. The amount of organic load, N and P, and organic carbon concentration can be reduced by prior collection of manure before wash down, which will reduce effluent loading with high concentration of pollutants [24]. Phytoremediation of abattoir wastewater is a suitable technology to manage nutrients and metals [56]. Abattoir wastewater is a richest source of N and P; hence it can be treated as an alternative source of

nutrients provider for poor fertile soil [56, 57]. The following steps are important for waste reduction and low –cost wastewater treatment techniques,

• The discharged wastewater should not exceed the acceptable level nutrients and pollutants.

• Microbial community should be eradicated through disinfection to ensure no pathogens and minimise bio threats.

• The environmental standards (legislation/law) defined by the state environmental authority / EPA should be strictly followed.

• Pollution levels to be reduced through various treatment techniques to retain the environmental quality.

• Nutrients (N and P) levels are maintained in the permissible level of discharge.

• To avoid odour emissions a considerable amount BOD to be reduced.

• Removal of organic, solids, fats, oil and grease to be done through various waste treatment process.

It is very important to ensure that "zero emission" standards of pollutants in the abattoir wastewater disposal are most satisfactory for various reuse process. Abattoir wastewater treatment system and its efficiency are directly influenced by various factors. Low cost / cost effective treatment technologies, available space / site, site sensitivity to odour, characterisation of treatment system, labour availability / mechanical energy, electrical energy / power, transport facility and climate these driving force applicable to vary in place to place [58].

6. Conclusions and research needs

Globally re-use of wastewater has been steadily increased in the volume of water in crop production. Wastewater irrigation fulfils 1% of the Australian agricultural water demand by re-use. Wastewater acts as both water source and nutrient supplement. This is added benefit to agricultural sector especially water scarce region. This proposed sustainable concept illustrated in Figure 5, Phytoremediation of contaminated land with abattoir effluents using high biomass producing plant species can be a cost effective technology to convert contaminated lands into cultivable land. Consequently the plants used not only act as remediators, but the biomass produced can also be used for energy production, paper production and feed for grazing animals. The Australian National Water Commission-2011[59] water initiative encourages various wastewater reuses and recycling research, and development programs especially cost effective technology to meet the national water demand both current and future. Wastewater reuse is an important component of sustainable water resource management, water reuse from various wastewater sources after removing the pollutants, nutrients and pathogens provide scope for water security.
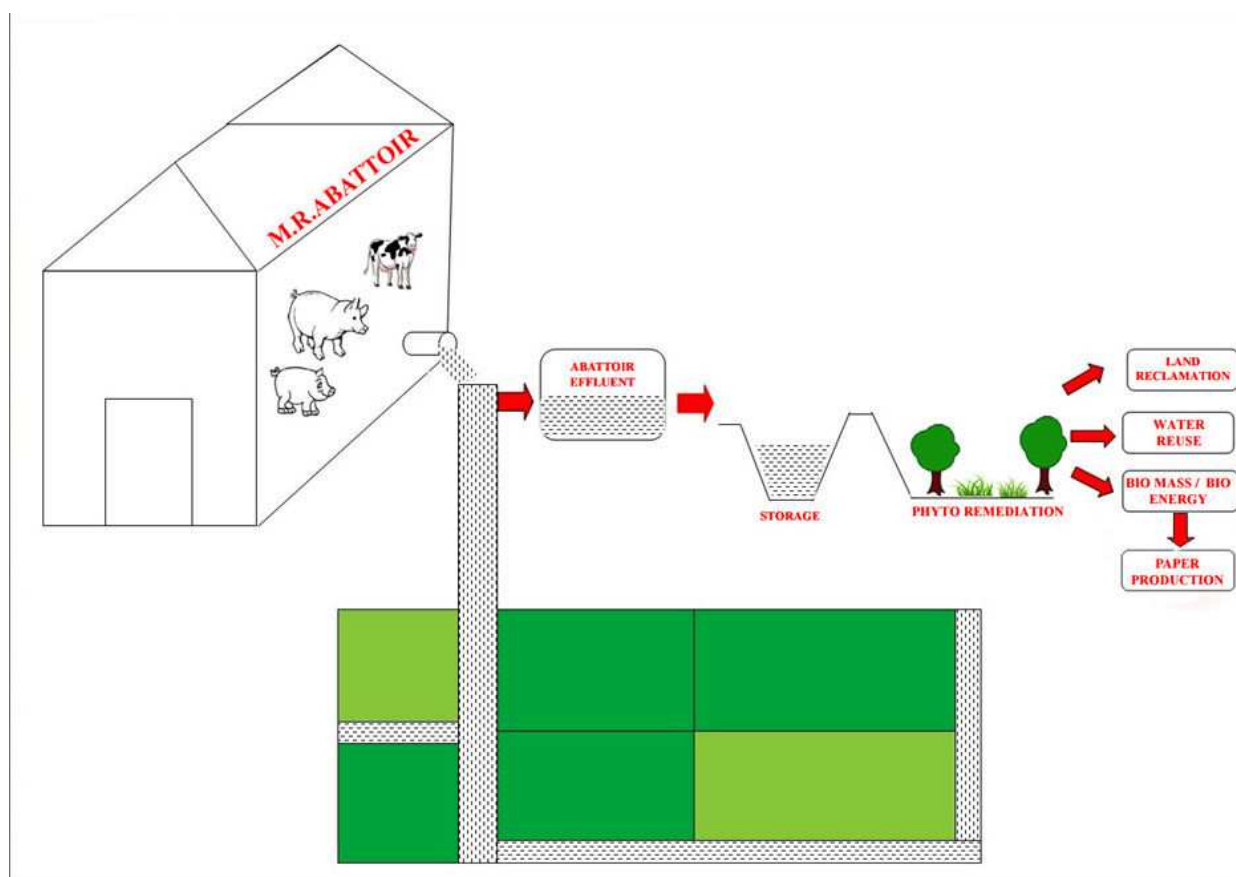
Figure 5. Conceptual framework of an effective low cost treatment plan for abattoir wastewater

Acknowledgements

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