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Water consumption, wastewater generation and characterization of a slaughterhouse for resource conservation and recovery

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ABSTRACT

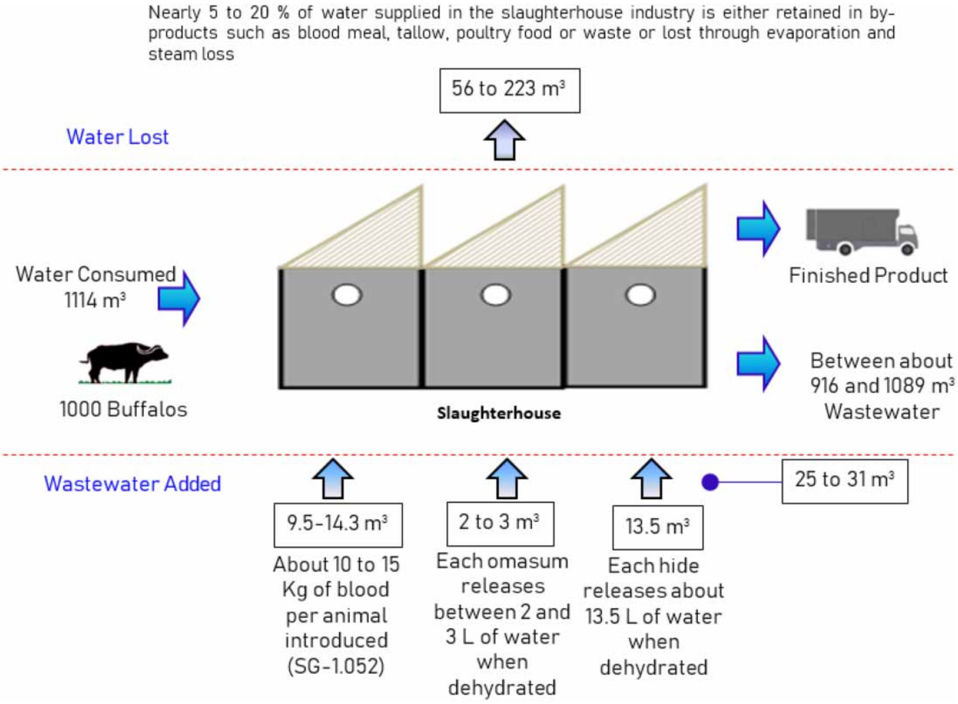
This study is an overview of a beef-based slaughterhouse's processes and operations, from animal reception to product dispatch, including water consumption over 105 days. On average, 1,114 L/buffalo is required for slaughter and processing. Corresponding wastewater generation is between 916 and 1,089 L. Water consumption per buffalo decreases with increasing numbers of buffalos slaughtered per day, and in some operations – e.g., plant washing, personal hygiene, canteen, and knife and instrument washing – is independent of the number of buffalo slaughtered. In contrast, refrigeration depends partly on the numbers slaughtered. Wastewater characterization from each slaughterhouse process and operation was carried out over three months, and wastewater physico-chemical characteristics from individual operations are presented.

Key words: resource recovery, reuse, slaughterhouse, water consumption, wastewater generation

HIGHLIGHTS

- Wastewater obtained from different slaughtering processes/operations has wide variation in characteristics in terms of SS, O &G, COD & BOD.
- Conventionally, wastewater is treated from all slaughtering operations in a combined manner.
- Segregation of various streams is highly recommended for treatment and potential resource recovery.

GRAPHICAL ABSTRACT



ACRONYMS AND ABBREVIATIONS

APEDA	Agricultural and Processed Food Export Development Authority
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EPA	Environmental Protection Act
ETP	Effluent Treatment Plant
FAO	Food and Agriculture Organization
FS	Floating Solids
FSSAI	Food Standards and Safety Authority of India
GoI	Government of India
HACCP	Hazard Analysis and Critical Control Points
ISO	International Standards Organization
MoEF	Ministry of Environment and Forest
MT	Metric Tonne
O&G	Oil & Grease
SG	Specific Gravity
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TLWK	Tonne of Live Weight Killed
TP	Total Phosphate
TS	Total Solids
TSS	Total Suspended Solids
TVS	Total Volatile Solids
USEPA	United States Environmental Protection Agency

INTRODUCTION

Slaughterhouses pose significant environmental challenges in water, soil, and land pollution. Global market integration and commercialization significantly increase the volume of animal waste (Haan *et al.* 1997). Increasing demand for meat products resulting from population growth has resulted in slaughterhouse-related pollution problems.

Slaughterhouse waste includes solids (bones, hooves, rumen, intestinal content, dung, etc.) and liquids (blood, urine, internal body fluids, washing and cleaning waters, etc.). If these wastes are not managed adequately and efficiently, they can harm the environment. Robert (2005) reported that waste disposal has always dominated the slaughtering sector and that, on average, 45% of each live beef animal consists of non-meat substances (bones, skin, teeth, hooves, etc.). A survey in India by Singh *et al.* (2014) revealed that no special disposal systems are used, the solid waste is either thrown and dumped in open fields, or sold to other parties. It becomes important, therefore, to use such a large amount of waste in an integrated and sustainable manner.

Many physico-chemical characterizations have been made of slaughterhouse industrial wastewater. A dedicated study is missing, however, evaluating the physico-chemical characteristics of wastewaters from individual slaughtering processes/operations. The aim of this study was to identify, characterize, and quantify slaughterhouse wastewater from individual processes/operations, to help in designing and implementing an effective and economical wastewater treatment facility. Identification has also been attempted of those areas where valuable resources can be recovered and water conserved.

METHODOLOGY

Approach and study area

In this study, the water consumption pattern in slaughterhouse processes and operations, and areas for improvement in water budgeting and waste minimization were identified on the basis of detailed wastewater characterization, to optimize energy and water consumption, and save resources.

A modern, integrated abattoir and meat manufacturing and export plant was selected for study in Uttar Pradesh, India. The plant operates to international standards and is HACCP, ISO 22000:2005, and 9001:2015 certified. The plant's main offering is fresh, boneless buffalo meat. It is classified as a 'large slaughterhouse' since its annual slaughtering capacity exceeds 40,000 cattle or dry live weight per day exceeding 70 tonnes (EPA Act [India] 1986). The plant has consent to slaughter 1,100 buffalos per day by APEDA, Ministry of Commerce, GoI, and consent to operate from the Uttar Pradesh Pollution Control Board. It is also licensed by FSSAI under the Food Safety & Standards Act (2006).

Water balance study

Groundwater, drawn from two wells, is the plant's primary water supply. The two pumps extract 90 and 130 m^3/hr, respectively, into an overhead tank. The groundwater's characteristics are presented in Table 1. Electromagnetic digital flow meters installed on the pump heads are used to measure daily and cumulative water consumption. Manual, analog, fin-type water meters are installed elsewhere to measure water consumption in different sections of the plant. Water consumption was measured daily at 08.00 from 1 April to 13 July, 2018 (105 days – no readings were taken from 14 to 18 June, due to holidays). The plant does not operate on Fridays, so the consumption on Fridays relates to plant washing and refrigeration, since all slaughterhouse processes and operations are closed. The water consumption studies were initiated first in order to regulate the water supply, since water consumption has direct influence on wastewater generation and characteristics.

Table 1 | Groundwater characteristics as supplied to the slaughterhouse

Parameters	Mean concentration*	Range
pH	7.35	7.2–7.6
Turbidity	1.0 NTU	–
Color	Less than 5 Hazen units	–
TDS	456 mg/L	425–490 mg/L
Total hardness	256 mg-$CaCO_3$/L	230–285 mg-$CaCO_3$/L
Chloride	24 mg-Cl^-/L	18–31 mg-Cl^-/L

*Mean of five, monthly, sampling events (April to August, 2018).

Sampling and analysis

The wastewater from each slaughterhouse process/operation is retained in a holding tank before release to the drains. The holding tanks are equipped with agitators and retain wastewater for between 30 and 60 minutes. Samples from individual slaughterhouse processes/operations were collected from the respective holding tanks in 1-liter plastic containers three times in a day and were then mixed to form a single, representative 3-liter sample. The representative sample was then analyzed for COD, BOD, TSS, TDS, TS, O & G, TKN and TP, following APHA standard procedures (APHA 2005). This exercise was carried out once in a month during August to October 2018.

RESULTS AND DISCUSSION

Processes and operations

The plant's processes involve numerous different operations. The wastewater streams generated from the processes are presented in Figure 1.

Animal reception and lairage

In lairage, buffalos are received and rested before slaughter, to help them recover from the journey to normal conditions. In order to recover as many solids as possible in dry form, cattle dung and bedding are scraped from delivery vehicles and holding areas, and frequent cleaning is necessary to maintain adequate hygiene. This is done by washing the floor regularly. Table 2 presents the wastewater characteristics from the lairage and subsequent sections. Wastewater from lairage contains fully digested suspended solids introduced from cattle dung excreted while resting.

The SS concentration in lairage wastewater depends on the amount of water used to wash the floor. To minimize the solids load from this section, laborers are encouraged to dry scrape dung as much as possible. Lairage wastewater has very high COD_{total} – 19,250 to 23,450 mg/L – while $COD_{soluble}$ is between 554 and 986 mg/L. Lairage wash water and manure are nutrient-rich and can be used as fertilizer (IPPC 2003).

Sticking/halal point

The next process is sticking (locally known as halal point), where cattle are slaughtered by cutting the main blood vessels in the neck, causing the loss of around 40 to 60% of the animal's blood (Wilson 2005). The blood goes to a tank just under a sticking/halal point and is pumped on for further processing or treatment. The sticking point wastewater characteristics are shown in Table 2. Blood is the main organic load contributor in slaughterhouse effluent, which has very high COD of around 375,000 mg/L (Sarairah & Jamrah 2008).

Blood clots naturally and quickly, but several anticoagulants – for example, sodium citrate, heparin, and EDTA – can be used to prevent and/or slow this (Bah *et al.* 2013). Clots start to form in blood in less than 5 seconds, however, and when thrombin is diluted in the ratio of 1:36, clotting starts in less than 15 seconds (Thomazini-santos *et al.* 1998). Analysis of blood stream SS was impractical since small, coagulated particles stop on filter paper raising the SS value during analysis, so only TS was determined for the sticking point wastewater. Both COD and BOD were determined, however, to assess the location's organic load contribution. The wastewater COD from this section varies between 31,600 and 121,600 mg/L, and the TKN is high, in the range 2,091 to 3,569 mg/L. The considerable variation in the wastewater COD is thought to occur because the floor of this section is washed continuously with a high-pressure nozzle to remove the blood. The amount of wash water could be controlled by using vipers to remove blood from the floor, and a slight gradient would help maximize blood capture and facilitate cleaning.

Hide removal, fleshing

Dehiding/hide removal is usually done manually by experienced personnel (USEPA 2002; FAO 2004) and safeguards carcasses from contamination. The process is completed with mechanical pullers' help, removing hide from neck to tail after the initial cut. The excess flesh and fat stuck to the hides are removed manually or by fleshing machine, wherein the hide is pressed between rollers while water is poured on continuously. Wet fleshing results in the loss of around 10 to 15% of the raw weight of the hides/skins (ENVIS 2015).

Fleshing section wastewater contains fine meat and fat particles – see Table 2 for its other principal characteristics. The SS concentration was found to be between 229,310 and 285,450 mg/L, and consists mostly of flesh, meat pieces, and skin fat. It seems very likely that this concentration range is overestimated, because the particle sizes are uneven, which can increase SS values significantly. It was observed that SS in wastewater from the fleshing section were floating. Floating meat pieces (hereinafter floating solids (FS)) occupied 50 to 80 mL per liter of wastewater. The $COD_{soluble}$ of the wastewater from the hide storage section was 80,560 to 164,800 mg/L. This high value of $COD_{soluble}$ is because of the washing of blood stuck on hides.

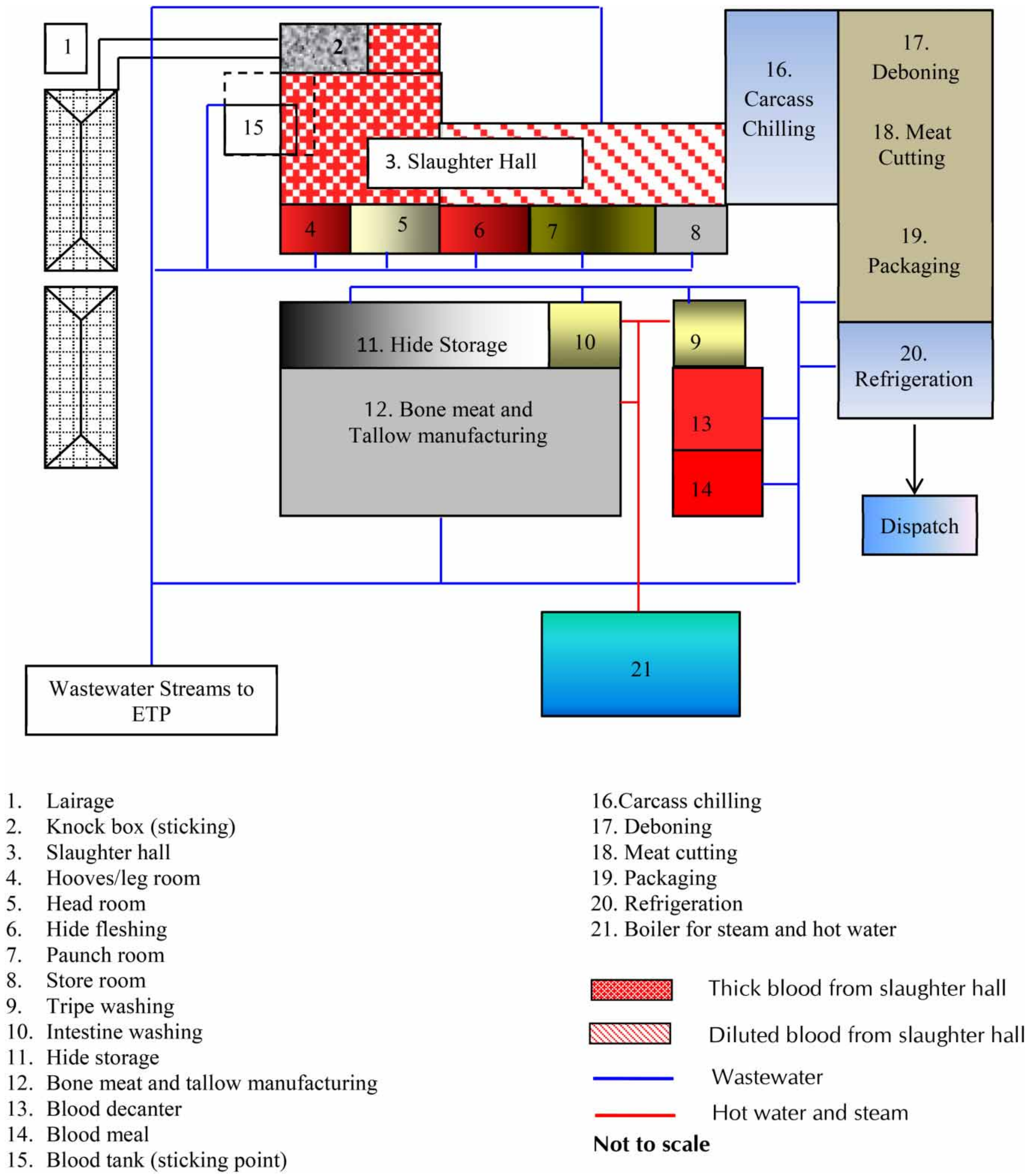


Figure 1 | Slaughterhouse and meat processing plant.

Hide storage

Hides are composed largely of water (65% moisture), the rest being proteins and fats (30 to 35%). Moist conditions favor bacterial proliferation, degrading the hides. To prevent this, the hides are dehydrated using sodium chloride (NaCl), applied in the order of 30 to 45% of the hide's weight (MoEF 2010). On average, 3 kg of NaCl is applied on small buffalo hides and 5 kg on big ones. The characteristics of the saline water from the hides are presented in Table 2. While the wastewater is slightly red from blood stuck to the hide, its COD cannot be determined because of the high chloride concentration as chloride interferes with the COD test (Southway 1981). Instead, the wastewater's organic strength can be considered in terms of the total volatile solids (TVS) concentration, which was in the range 7,350 to 9,940 mg/L. The TDS concentration was between 257,602 and 323,534 mg/L, mainly because of the NaCl applied to the hides.

Table 2 | Slaughterhouse processes and operations – wastewater characteristics

Parameters	Slaughterhouse processes and operations									
	Lairage	Sticking	Fleshing	Hide storage	Paunch room	Slaughter hall	Intestine washing	Tripe washing	Omasum dehydration	Rendering
pH	6.26–6.65	6.75–6.60	6.2–6.6	6.9–7.1	6.40–6.75	6.50–6.82	6.5–7.8	6.2–7.5	6.4–6.5	6.3–7.9
TS	–	14,340–19,460	–	–	–	–	–	–	–	–
SS	6,880–15,260	–	229,310–285,450	17,960–27,980	10,120–25,250	2,110–2,560	4,100–11,300	6,300–13,600	45,200–53,010	1,950–4,790
Floating solids	–	–	50 to 80	–	–	–	250–350	400–500	–	–
TDS	6,140–7,260	–	2,450–3,340	257,600–323,530	1,260–2,830	1,850–2,240	–	–	257,550–350,250	–
O & G	–	–	–	–	–	–	25,380–28,410	32,750–36,720	–	12,720–25,380
COD_{total}	19,250–23,540	31,600–121,600	–	–	31,680–45,460	4,250–5,120	–	–	–	23,400–58,000
$COD_{soluble}$	550–990	–	80,560–164,800	–	1,750–1,920	–	1,280–1,940	1,570–2,240	–	1,790–2,450
BOD_{3total}	8,860–12,010	11,210–48,330	–	–	10,770–13,300	1,870–2,150	–	–	–	–
$BOD_{3soluble}$	530–940	–	–	–	570–930	–	–	–	–	–
TKN	129–174	2,091–3,569	2,979–3,850	–	385–580	320–460	35–90^{S}	40–110^{S}	–	386–674
TP	3.58–8.7	34.02–58.26	39–64	–	2.98–18.5	3.0–5.4	9–32^{S}	12–28^{S}	–	55–196
TVS	–	–	–	7,350–9,940	–	–	–	–	7,500–7,740	–
Chloride	–	–	–	115,920–155,300	–	–	–	–	117,140–170,160	–
Previous studies	TS 5700–16,500 COD 6,550–17,300; BOD 2,660–9,670 (Cumby *et al.* 1999)	Raw blood COD 375,000; BOD 150,000–200,000 (Tritt & Schuchardt 1992)	The quantity of wet fleshings is in the range 10 to 15% of the raw hide weight (MoEF 2010)	Soak liquor TDS 40,000–60,000 (Kannan & Rao 2000)	BOD 18,000 (Mittal 2004) BOD 2,500–3,500 (Tritt & Schuchardt 1992)	COD 2,296 ± 747; BOD 2,174 ± 848 (Ziara *et al.* 2018)	No studies found for comparison.			

^{S}Represents values for $TKN_{soluble}$ and $TP_{soluble}$; All parameters except pH and floating solids are expressed in mg/L; floating solids are expressed in ml/L.

Evisceration

Evisceration is the process of removing the body's internal organs. Intestinal contents – paunch – which are partially digested, are major pollutants in slaughterhouses (Carawan & Pilkington 1986), and their wet weight is typically between 22 and 31 kg/animal (Carawan *et al.* 1979). Paunch is removed manually and excess solids stuck on the inner wall are washed out, which generates wastewater (Table 2). As can be seen, paunch wastewater is dominated by partially digested SS, unlike SS from lairage.

Carcass cutting and chilling

After evisceration, the carcass is split in two along the spinal cord. The cut carcasses are rinsed. The wastewater contains pieces of meat and bone, and its COD varies between 4,250 and 5,120 mg/L as it includes blood previously retained in the carcass. The carcasses are normally then kept in chillers at about 5 °C for 24 hours, after which they are sent for cutting and dispatch.

Intestine and tripe washing

The intestines and tripes (edible lining from the stomach) are washed at nearly 70 °C for between 6 and 15 minutes. Most of the solids from tripe washing are floatable, and 400 to 500 mL/L were found in tripe washing wastewater. The wastewater from intestine washing contained between about 250 and 350 mL/L of FS. It should be possible to recover FS for rendering.

Omasum washing

Omasum is the third compartment of the bovine stomach. It is dehydrated by applying NaCl for 15 minutes and then stirring for 15 minutes, after which the water squeezed out and discharged. On average about 0.25 to 0.33 kg of NaCl is applied and about 2 to 3 liters of wastewater is produced per omasum.

Rendering

Rendering starts with heating to remove moisture and separate the fat from the meat (Meeker & Hamilton 2006), to yield products including edible and inedible tallow, animal protein meal, soap, cosmetics, candles, perfumes, and paint (Swisher 2006). Rendering plant effluent contains oils, nutrients (from protein degradation), and pathogenic microorganisms, and has high oxygen demand (Sindt 2006). Most of the COD in rendering plant wastewater in this study arose from fine meat scraps, and the soluble COD concentration was in the range 1,785 to 2,450 mg/L.

Meat deboning, cutting, and packaging

Carcasses are finally deboned and cut according to consumer requirements, before being packed and stored. The holding and dispatch room is maintained at 2 to 4 °C. The wastewater from these sections derives mainly from washing – floors, working tables, packaging instruments, knives, and so on – and personal hygiene, and carries no significant organic load, so it was not characterized.

Comparison with the previous studies

No similar data to those from this study are available from past ones but some resemblances are apparent – see the bottom row (previous studies) in Table 2. Lairage wastewater, for instance, resembles that from livestock/dairy farms. Its characteristics in the slaughterhouse depend on the water used for floor washing and the amount of dung scraped off before washing. Similarly, Tritt & Schuchardt (1992) reported the COD and BOD of raw bovine blood from the sticking section. In the same section in this study, a lot of water is used continuously to clean blood from the floor, so the COD and BOD values reported here are lower because of the wash-water dilution.

Kannan & Rao (2000) reported that soak liquor TDS in tanneries was 40,000 to 60,000 mg/L, which is less than the TDS of wastewater from the hide storage section in this study. Joseph & Nithya (2009) reported that 300 kg of salt is used to preserve hides in the slaughterhouse industry per 100 m^2 of leather produced.

For paunch, there is wide variation in the BOD values reported by Mittal (2004) and Tritt & Schuchardt (1992). However, Tritt & Schuchardt (1992) report that paunch contains lignocellulose – for example, in straw, grass, and hay – and, as a result, BOD values are lower than COD. Ziara *et al.* (2018) report comparable COD and BOD values from carcass washing to those found here. No previous studies on effluent characteristics from intestine and tripe washing, or omasum dehydration were found. Black *et al.* (2013) report that fleshing generates effluent containing flesh particles in suspension and blood, as found in this study.

Water consumption

Water consumption was studied from 1 April to 13 July 13, 2018. The number of animals slaughtered depends on the availability of buffalos from local livestock farmers, which varies daily. Consumption monitoring was not possible on public holidays and the like, because all slaughtering operations are closed (Figure 2). On days

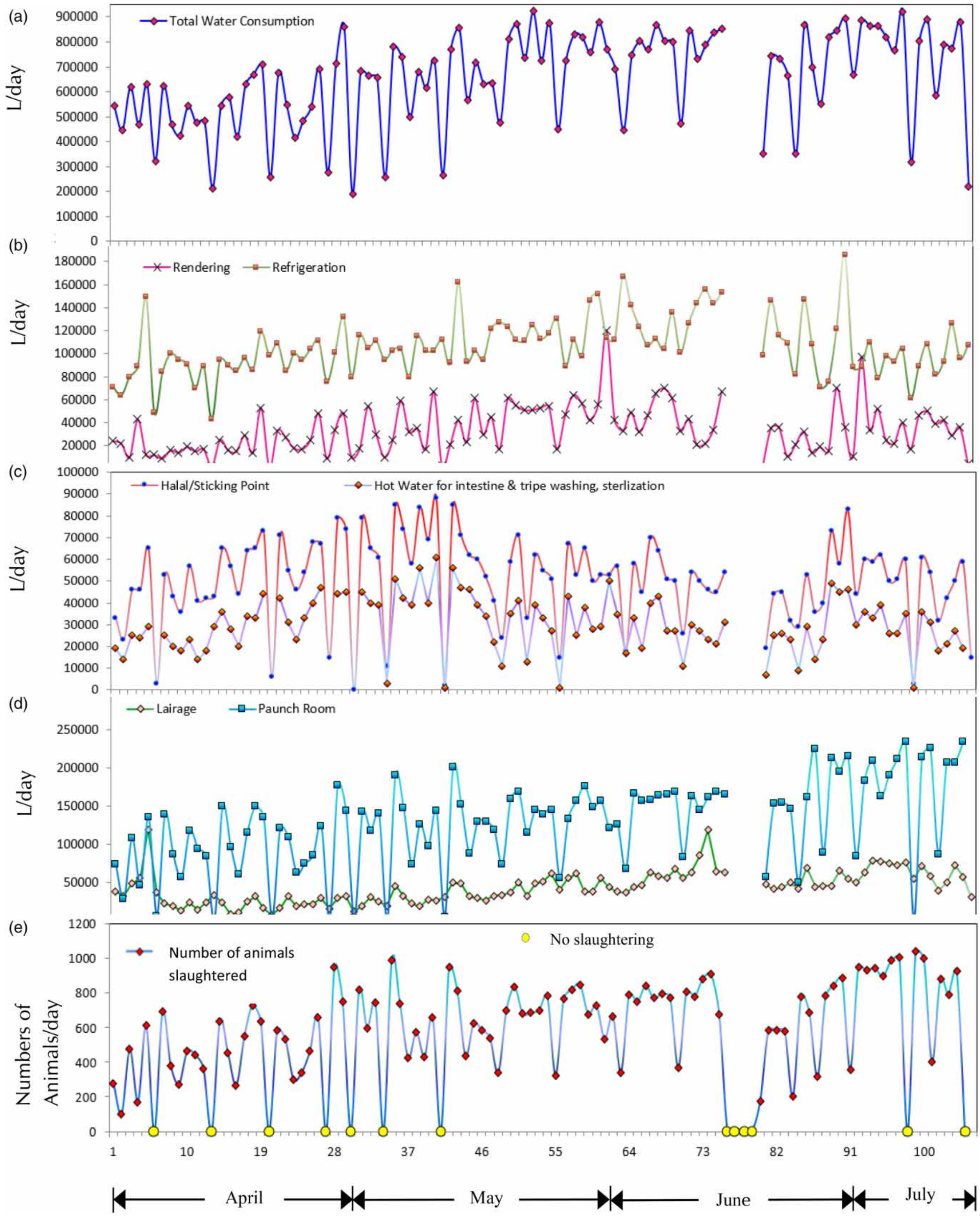


Figure 2 | Total and process-specific water consumption in slaughtering and meat-processing.

when slaughtering does not occur, water consumption reflects the requirements for plant washing and the refrigeration system. The plant is washed at the end of each day and the average requirement was 180 m^3/d – over the nine non-working event days – after allowing for consumption in refrigeration.

Total water consumption and that for some specific processes is shown in Figure 2. The slaughtering processes/operations where water meters are not installed include the slaughter hall (dehiding and carcass cutting), fleshing, intestine and tripe washing, plant washing, deboning, and cutting and packaging, as well as personal hygiene, the administrative building, knife washing and the canteen. The unmeasured flow was calculated by subtracting the measured flow (the processes/operations where water meters are installed) from the total water consumption (the main delivery pipeline to all the processes/operations). The unmeasured flow was nearly 45 to 55% of the total flow into the slaughterhouse.

Some 59,087 buffalos were slaughtered during the study period, and the corresponding water consumption was 65,868,806 L, showing that 1,114 L of water is required on average for one buffalo slaughtered and processed (Figure 3; pecked blue line). Average water consumption per buffalo for individual processes was also determined, and is presented in Table 3. Notably, water consumption per buffalo is highest for paunch washing, followed by refrigeration (the plant operates refrigeration for 300 tonnes of final product, as well as carcass chilling, meat cutting, and the packaging hall).

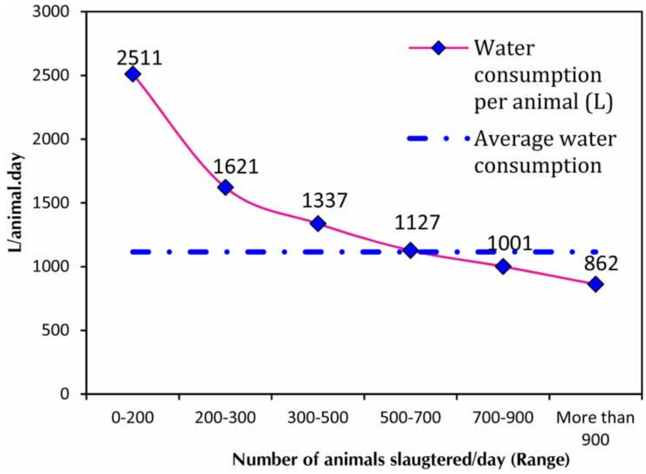


Figure 3 | Water consumption variation with increase in slaughtering numbers.

Table 3 | Average water consumption per buffalo

Operation	Average water consumption (L/animal)
1. Lairage	74
2. Sticking	86
3. Fleshing[a]	30
4. Paunch	215
5. Hot water[b]	49
6. Rendering	58
7. Carcass-cutting, dehiding, personal hygiene, administrative building, canteen, laundry	240
8. Plant washing[c]	180
9. Refrigeration	182
Average water consumption per animal	1,114

[a]Nearly 30 L water/hide is required for fleshing (separate study conducted).
[b]Hot water is required for sterilizing knives and instruments, rendering, and intestine and tripe washing.
[c]Water consumed for plant washing on holidays reflects water consumed on all days for plant washing.

A factor directly associated with water consumption is the degree of cleanliness required. Cleaning and hygiene practices in meat-related industries are usually stringent, which increases water use (COWI 2000). An increase of 20 to 25% in water consumption due to the HACCP program has been reported (USEPA 2002). Water consumption, in this study, was lower than that reported by either Johns (1995) (1.2 to 1.5 m^3/head) or Enterprise Ireland (2009) (1.0 to 3.7 m^3/head). Plants that keep monitoring their water use and wastewater flow continuously have been able to reduce water consumption by as much as 50% (Carawan *et al.* 1979). Employee training and constant monitoring of water use are proven ways of reducing water consumption in a plant (Bailone *et al.* 2020).

Wastewater generation

Not all water used in the slaughterhouse is discharged as wastewater. Between 5 and 20% of the water supplied is either retained in by-products – for example, blood meal, tallow, poultry food, and waste – or lost through evaporation and heating/steam (MRC 1995; Enterprise Ireland 2009). Some slaughterhouse operations add to the wastewater. Each buffalo releases nearly 10 to 15 kg of blood at the sticking point. As the specific gravity (SG) of buffalo blood is 1.052 (Chaplin *et al.* 1970), this represents between 9.5 to 14.3 L/animal. Between 2 and 3 L of water is released when the omasum is dehydrated, assuming that the average wet weight of an omasum is 3 kg and its moisture content falls from 70 to less than 3%. Each hide releases around 13.5 L of water – a hide's average wet weight is 27 kg and its moisture content brought down from 65% to below 30. Average water use and wastewater generation in this study from a slaughterhouse industry are shown in Figure 4.

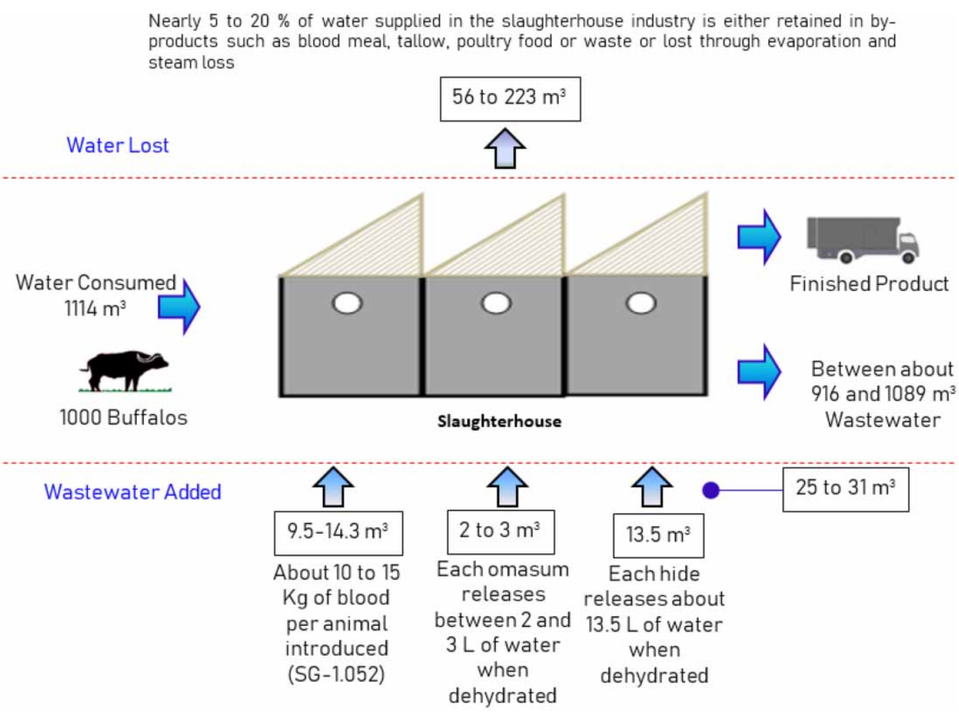


Figure 4 | Water use and wastewater generation in the slaughterhouse.

Potential scope for water reuse, conservation, and recovery

An attempt has been made to identify areas where water could potentially be reused, and/or useful products with commercial value recovered. The findings are based on water consumption patterns, wastewater characterization, and discussion with the industry, and are presented in Table 4.

CONCLUSIONS

Slaughterhouse operations are water intensive, in part because of the stringent food safety and sanitary norms prescribed by national and international organizations. On average, 1,114 L of water is required per buffalo for slaughter and processing, with wastewater generation between about 916 and 1,089 L. Per capita water consumption falls with increasing slaughter numbers per day.

Table 4 | Potential areas for water reuse and resource recovery

	Process/operation	Potential for water reuse/resource recovery
1.	Lairage	Fully digested dung solids could be recovered using suitable screening equipment for use as manure.
2.	Paunch	Partially digested intestinal content can be recovered using suitable screening equipment for use as boiler feed, after dewatering and drying.
3.	Sticking point	Blood collected from the drains to the tank could be sent to a decanter centrifuge to manufacture blood meal. This will remove a major portion of the organic load from discharge to the ETP
4.	Fleshing, intestine and tripe washing	Floating meat/flesh pieces can be recovered and sent for rendering.
5.	Refrigeration	Water used for refrigeration can be used directly for lairage washing, saving a substantial volume.
6.	Rendering	Steam from rendering can be condensed, then used for intestine and tripe washing, which require water at 60 to 70 °C.
7.	Omasum washing and hide storage	Common salts can be recovered, after organics removal and evaporation, for reuse in hide storage and omasum dehydration.
8.	Final treated water	Can be used for truck and lairage washing, gardening, and toilet flushing.

Slaughterhouse wastewater is characterized principally by biodegradable organic matter, but its characteristics vary widely in terms of organic strength, solids content, floating solids, and O&G from different slaughterhouse processes/operations. Wastewaters from the lairage and paunch sections contain fully and partially digested dung solids, respectively. Wastewaters from intestine and tripe cleaning, rendering, and hide fleshing contain FS and O & G. Blood from the sticking point exerts a very high organic load. Wastewaters from the hide storage and omasum dehydration areas contain NaCl.

There is ample scope for recovering resources like NaCl from the hide storage and omasum dehydration sections, dung from the lairage and paunch sections, and animal fats from the fleshing, and intestine and tripe washing sections.

It is usual to treat the wastewater streams from all slaughtering processes/operations together, making it difficult to achieve effluent quality within the permissible discharge limits. If the streams are segregated, however, on the basis of similarity, and managed separately, there will be benefits in terms of resource recovery, waste load reduction, and ease in wastewater treatment.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

American Public Health Association (APHA) 2005 *Standard Methods for the Examination of Water and Wastewater,* 21st edn. APHA, Washington, DC.

Bah, C. S., Bekhit, A., Carne, A. & McConnell, M. A. 2013 Slaughterhouse blood: an emerging source of bioactive compounds. *Comprehensive Reviews in Food Science and Food Safety* **10**, 314–331.

Bailone, R., Roça, R., Fukushima, H. & de Aguiar, L. K. 2020 Sustainable water management in slaughterhouses by cleaner production methods – a review. *Renewable Agriculture and Food Systems* **36**, 1–10.

Black, M., Canova, M., Rydin, S., Scalet, B. M., Roudier, S. & Sancho, L. D. 2013 *Best Available Techniques (BAT) Reference Document on for the Tanning of Hides and Skin.* European Union, Luxembourg.

Carawan, R. E. & Pilkington, D. H. 1986 *Reduction in Waste Load From A Meat Processing Plant-Beef.* North Carolina Agricultural Extension Service, Raleigh, North Carolina, USA.

Carawan, R. E., Chambers, J. V. & Zall, R. R. 1979 *Meat Processing Water and Wastewater Management.* North Carolina Agricultural Extension Service, Raleigh, North Carolina, USA.

Chaplin, R. K., Waldern, D. E. & Frost, O. L. 1970 Specific gravity of bovine blood as affected by breed and age. *American Journal of Veterinary Research* **31**, 1887–1888.

COWI Consulting engineers and planners 2000 *Cleaner Production Assessment in Meat Processing.* United Nations Environment Programme, Division of Technology, Industry and Economics and Danish Environmental Protection Agency, Nairobi, Kenya.

Cumby, T. R., Brewer, A. J. & Dimmock, S. J. 1999 Dirty water from dairy farms, I: biochemical characteristics. *Bioresource Technology* **67**(2), 155–160.

Enterprise Ireland: Transforming Irish Industry 2009 *Sustainable Practices in Irish Beef Processing.* National Development Plan, Government of Ireland, Dublin.

Environmental Protection Act (EPA Act), GoI 1986 Guideline 12(i), Schedule III, Annexure 5.1. Government of India, New Delhi.

ENVIS Centre on: Cleaner Production/Technology, Ministry of Environment & Forest, GoI 2015 Cleaner Production Guidelines in Leather Industries. Government of India, New Delhi.

Food and Agriculture Organization (FAO), United Nations 2004 *Good Practices for the Meat Industry.* Food and Agricultural Organization, Rome, Italy.

Food Safety and Standards Act, India 2006 Available from: https://www.fssai.gov.in/upload/uploadfiles/files/FOOD-ACT.pdf Accessed on October 20, 2021.

Haan, C., Steinfeld, H. & Blackburn, H. D. 1997 *Livestock & the Environment: Finding A Balance.* Food and Agricultural Organization, Rome, Italy.

Integrated Pollution Prevention and Control (IPPC). 2003 *Guidance for the Red Meat Processing (Cattle, Sheep and Pigs) Sector, 1.* Environment Agency, Bristol, United Kingdom.

Johns, M. R. 1995 Development in wastewater treatment in the meat processing industry: a review. *Bioresource Technology* **54**(3), 203–216.

Joseph, K. & Nithya, N. 2009 Material flows in the life cycle of leather. *Journal of Cleaner Production* **17**(7), 676–682.

Kannan, C. S. & Rao, P. G. 2000 A study of the design of solar evaporation pans. *Indian Journal of Chemical Technology* **17**, 326–331.

Meat Research Corporation (MRC). 1995 *Identification of Nutrient Sources, Reduction Opportunities and Treatment Options for Australian Abattoirs and Rendering Plants.* Meat & Livestock Australia Limited, North Sydney, Australia.

Meeker, D. & Hamilton, C. R. 2006 *In Essential Rendering Edited by David L. Meeker: An Overview of the Rendering Industry*. National Renderers Association, Virginia, USA.

Ministry of Environment and Forest (MoEF) (GoI). 2010 *Manual: Leather/Skin/Hide Processing Industry*. MoEF, New Delhi.

Mittal, G. S. 2004 Characterization of the effluent wastewater from abattoirs for land application. *Food Reviews International* **20**(3), 229–256.

Robert, F. 2005 *Meat Packing Industry. Microsoft Encarta Encyclopedia Standard.* Microsoft, Redmond, WA.

Sarairah, A. & Jamrah, A. 2008 Characterization and assessment of treatability of wastewater generated in Amman slaughterhouse. *Dirasat Engineering Science* **35**(2), 71–83.

Sindt, G. L. 2006 *In Essential Rendering Edited by David L. Meeker: Environmental Issues in the Rendering Industry*. National Renderers Association, Virginia, USA.

Singh, A. L., Jamal, S., Baba, S. A. & Islam, M. M. 2014 Environmental and health impacts from slaughter houses located on the City Outskirts: a case study. *Journal of Environmental Protection* **5**, 566–575.

Southway, C. 1981 *The Chemical Oxygen Demand Test: Final Report on the Investigation Made During the Period Oct. 1977-Oct. 1980.* University of Salford, Manchester, United Kingdom.

Swisher, K. J. 2006 *In Essential Rendering Edited by David L Meeker: The Global Market for Rendered Products.* National Renderers Association, Virginia, USA.

Thomazini-santos, I., Giannini, M., Jose, M., Toscano, E., Machado, P. E. A., Lima, C. & Barraviera, B. 1998 The evaluation of clotting time in bovine thrombin, reptilase, and thrombin-like fraction of Crotalus durissus terrificus venom using bovine, equine, ovine, bubaline and human cryoprecipitates. *Journal of Venomous Animals and Toxins* **4**(2).

Tritt, W. P. & Schuchardt, F. 1992 Materials flow and possibilities of treating liquid and solid wastes from slaughterhouses in Germany. A review. *Bioresource Technology* **41**(3), 235–245.

United States Environmental Protection Agency (USEPA) 2002 *Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Meat and Poultry Products Industry Point Source Category*. USEPA, Washington, DC, USA.

Wilson, A. 2005 *Handbook on Practical Meat's Inspection.* Blackwell Publishing Ltd, Hoboken, New Jersey, USA.

Ziara, R. M. M., Li, S., Subbiah, J. & Dvorak, B. I. 2018 Characterization of wastewater in two U.S. cattle slaughterhouses. *Water Environment Research* **90**(9), 851–863.

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