# Tanneries in Kanpur, India, Water Pollution in the Ganges, and Unitization

Batabyal, Amitrajeet

Rochester Institute of Technology

16 December 2024

# Tanneries in Kanpur, India, Water Pollution in the Ganges, and Unitization [1]

by

AMITRAJEET A. BATABYAL,[2]

[1] For their helpful comments on a previous version of this paper, I thank the Editor-in-Chief Yoshiro Higano, two anonymous reviewers, and session participants in the Southern Regional Science Association Annual Conference in Louisville, Kentucky, April 3-5, 2025. In addition, I acknowledge financial support from the Gosnell endowment at RIT. The usual absolution applies.

[2] Departments of Economics and Sustainability, Rochester Institute of Technology, 92 Lomb Memorial Drive, Rochester, NY 14623-5604, USA. E-mail: aabgsh@rit.edu

# Tanneries in Kanpur, India, Water Pollution in the Ganges, and Unitization

Abstract

We analyzed water pollution in the Ganges River caused by tanneries in Kanpur, India. Specifically, we examined the merits of a claim made recently in the literature that unitizing or merging polluting tanneries can improve water quality in the Ganges. We modeled the $n \geq 2$ polluting tanneries in Kanpur as a Cournot oligopoly and derived the equilibrium output of leather, profits, and social welfare. Second, we permitted $m < n$ tanneries to merge and determined when the $m$-tannery unitization is profitable to the unitized entity. Third, the $(n - m)$ non-unitized tanneries were better off with unitization. Finally, our findings demonstrated that $m$-tannery unitization increases the industry price of leather and lowers social welfare. In conclusion, we discuss the implications of these findings for improved water quality in the Ganges.

**Keywords:** Ganges River, Social Welfare, Tannery, Unitization, Water Pollution

**JEL Codes:** G34, Q25, Q28

# 1. Introduction

## *1.1. Preliminaries*

Along the banks of the sacred Ganges River in Kanpur, a silent crisis brews beneath the surface—one fueled by the city's sprawling leather manufacturing or tannery industry. Hundreds of tanneries, once symbols of economic pride, now pump between 5.8 and 8.8 million liters of toxic wastewater into the river each day (Chaudhary and Walker 2019). Laden with chromium, arsenic, and other hazardous chemicals, this effluent not only turns the river's waters a murky brown but also poisons the very lifeline that sustains millions (Khwaja *et al.* 2001; Arya and Gupta 2013). The Ganges, revered as a goddess by millions of Hindus, is being desecrated daily in the name of industrial profit, turning spiritual devotion into a health hazard (Mallet 2017).

The impact is catastrophic—not just for aquatic life but for entire communities that rely on the river for drinking, bathing, and agriculture. Fishermen haul in dead, discolored fish, farmers irrigate their crops with tainted water, and children play, unaware of the invisible toxins swirling around them (Markandya and Murty 2004; Singh and Rao 2013). Despite government regulations and court orders, enforcement remains weak, and the tanneries continue to operate with impunity (Chakraborty and Chakraborty 2007). As a result, what was once a river of purity is now a flowing symbol of negligence, greed, and environmental decay, a crisis demanding urgent, uncompromising action (Batabyal 2023).

What is needed, to address the underlying issue, is a multi-pronged approach involving stricter regulatory frameworks, modernized treatment facilities, and sustainable practices within the leather industry (Ingle *et al.* 2011). Advanced effluent treatment technologies and the adoption of eco-friendly tanning methods can significantly reduce the environmental footprint of tanneries. Community involvement, coupled with awareness campaigns, is also crucial to building local support for cleaner industrial practices (Das and Tamminga 2012). Ultimately, preserving the Ganges from further degradation is not just an environmental challenge but a social and moral imperative for ensuring the health, prosperity, and cultural identity of millions who hold the river sacred.

Notwithstanding the significance of the water pollution problem in the Ganges in Kanpur, there are very few studies in the extant literature that have rigorously analyzed this problem. Recently, Batabyal (2023) and Batabyal *et al.* (2023) have theoretically analyzed facets of the Ganges water pollution problem in Kanpur. Both papers concentrate on the water pollution caused by two tanneries, one located upstream of the other. Batabyal (2023) concentrates primarily on how the production of leather is altered by clearly accounting for water pollution whereas Batabyal *et al.* (2023) are more concerned with how leather production is affected by the nexuses between global warming and water pollution.

*1.2 Our objective*

A salient point that we would now like to emphasize is that both analyses maintain that one way to ensure higher water quality in the Ganges is by unitizing or merging[3] the two polluting tanneries under study. For example, Batabyal *et al.* (2023, p. 11) say that "a straightforward policy implication of our analysis is that a number of these polluting tanneries ought to be merged into larger entities. Such an action is likely to ameliorate water quality in the Ganges."

To the best of our knowledge, the virtues of unitization or a merger in the setting of polluting tanneries in Kanpur has *not* been studied previously in the literature. Therefore, our objective in this paper is to examine the virtues of the unitization assertion made by Batabyal (2023) and Batabyal *et al.* (2023).

Section 2 below adapts the model in Salant *et al.* (1983) and describes the $n \geq 2$ polluting tanneries in Kanpur as a Cournot oligopoly and derives the equilibrium output of leather, profits, and social welfare. Section 3 permits $m < n$ tanneries to merge and then determines when the $m$-tannery unitization is profitable to the unitized entity. Section 4 shows that the $(n - m)$ non-unitized tanneries are better off with unitization. Section 5

---

3 We shall use the terms "unitization" and "merger" interchangeably in the remainder of this paper. See Hartwick and Olewiler (1998, p. 194) for a textbook exposition of unitization in the natural resource and environmental economics literature.

points out that the $m$-tannery unitization increases the industry price of leather and lowers social welfare. Section 6 discusses the implications of our findings for improved water quality in the Ganges. Section 7 concludes and then suggests two ways in which the research described in this paper might be extended.

## 2. The Cournot Oligopoly

There are approximately 400 tanneries in the Kanpur region and many of these tanneries are responsible for water pollution in the Ganges (McBride 2014). Hence, to substantively address the benefits of unitization, we shall depart from the focus of Batabyal (2023) and Batabyal *et al.* (2023) on $n = 2$ tanneries and consider a stylized version of the Kanpur economy in which there are $n \geq 2$ tanneries.

We shall think of these $n \geq 2$ tanneries collectively as a Cournot oligopoly.[4] The quantity of leather produced by the $ith$ tannery is $q_i \geq 0, i = 1, \dots, n$. Total production of leather is given by $Q = \sum_{i=1}^{n} q_i$. Because $q_i \geq 0$ for $i = 1, \dots, n$, it follows that $Q \geq 0$. The inverse demand function for leather in our $n$ tannery leather manufacturing industry is given by $P(Q) = a - bQ$, where $a > 0$ and $b > 0$.

There are two kinds of costs in producing leather that are incurred by individual tanneries. The first cost is the direct cost of producing leather which is described by the

4

See Tirole (1988, pp. 218-221) for a textbook discussion of a Cournot oligopoly. An alternate modeling strategy would be to think of these $n$ tanneries as a Bertrand oligopoly.

linear and weakly convex cost function $\alpha q, \alpha > 0$. The second or indirect cost stems from the *requirement* that tanneries treat the waste they give rise to (Singh and Gundimeda 2021). Let us delineate this cost with the linear and weakly convex cost function $\beta q, \beta > 0$. Hence, the full cost of producing leather confronting an arbitrary tannery is $C(q) = \alpha q + \beta q = (\alpha + \beta)q = \zeta q$ where $\alpha + \beta = \zeta, \alpha \neq \beta$, and $a > \zeta$.

The reader should note that if the tanneries under study do not treat the waste at all or if they insufficiently treat this waste then one way to account for this scenario would be to posit a lowering of the magnitude of $\beta$ from, say, $\hat{\beta}$ to $\check{\beta}$ where $\hat{\beta} > \check{\beta}$. With this description of the theoretical framework in place, our next task is to determine the Cournot equilibrium output of leather, profits, and social welfare.

We now use standard game-theoretic techniques---see Ioan and Ioan (2025) for example---to obtain the symmetric equilibrium values of the output of leather, price, profits, and social welfare in our $n$-tannery leather-manufacturing industry. To this end, let $q_n$ denote the per tannery output of leather, $Q_n$ denote the Kanpur tannery industry output of leather, $P_n$ denote the equilibrium price of leather, and $\pi_n$ denote the per tannery equilibrium profit. We state our first result in

*Proposition 1.* In the symmetric equilibrium, $q_n = (a - \zeta)/\{b(1+n)\}$ and $Q_n = \{(a - \zeta)n\}/\{b(1+n)\}$.

*Proof.* The $ith$ tannery chooses output $q_i$ to maximize profit given by $\pi_i = (a - bQ)q_i - \zeta q_i$. The first-order necessary condition for a maximum to this problem is $a - 2bq_i - bQ_{-i} - \zeta = 0$ where $Q_{-i} = \sum_{\forall j \neq i} Q_j$. In a symmetric equilibrium, $q_i = q, \forall i \Rightarrow Q = nq$ and $Q_{-i} = (n-1)Q$. Substituting this value of $Q_{-i}$ into the first-order necessary condition and then simplifying the resulting expression gives us $a - bq(1+n) - \zeta = 0$. Solving this last equation for $q$ and then replacing $q$ with $q_n$ gives us $q_n = (a-\zeta)/\{b(1+n)\}$. Substituting this value of $q_n$ into $Q_n = nq_n \Rightarrow Q_n = \{(a-\zeta)n\}/\{b(1+n)\}$. Finally, writing these two equilibrium output values together, we get

$$q_n = \frac{a-\zeta}{b(1+n)}, Q_n = \frac{(a-\zeta)n}{b(1+n)}. \blacksquare \qquad (1)$$

Having obtained the equilibrium individual tannery output and industry output of leather in Proposition 1, we can now derive the industry price of leather $P_n$ and the individual profit obtained by each tannery or $\pi_n$. We get

*Proposition 2.* In the symmetric equilibrium, $P_n = (a + \zeta n)/(1+n)$ and $\pi_n = (a-\zeta)^2/\{b(1+n)^2\}$.

*Proof.* Substituting the value of $Q_n$ from equation (1) into the inverse demand function for leather gives us $P_n = a - bQ_n \Rightarrow P_n = a - b\{n(a-\zeta)/(1+n)\}$. Simplifying this last expression gives $P_n = (a+\zeta n)/(1+n)$. Next, substituting this value of $P_n$ and the value of $q_n$ from equation (1) into the individual tannery profit function gives $\pi_n = (P_n - \zeta)q_n = \{(a+n\zeta)/(1+n) - \zeta\}[(a-\zeta)/\{b(1+n)\}]$. Simplifying this last expression gives $\pi_n =$

$(a-\zeta)^2/\{b(1+n)^2\}$. Finally, writing these two equilibrium values of the price and per tannery profit together, we obtain

$$P_n = \frac{a+\zeta n}{(1+n)}, \pi_n = \frac{(a-\zeta)^2}{b(1+n)^2}. \blacksquare \tag{2}$$

Let us now compute social welfare or $SW_n$ in our stylized Kanpur economy. The closed-form expression for social welfare is given in

*Proposition 3.* Social welfare or $SW_n = \{(a-\zeta)^2 n(2+n)\}/\{(2b(1+n)^2\}$.

*Proof.* Using the equation for the inverse demand function, we can express social welfare as $SW_n = \int_0^{Q_n}(a-bQ)dQ - \zeta Q_n$. Calculating the integral on the right-hand-side (RHS) of the expression for $SW_n$ and then substituting for $Q_n$ from equation (1) gives us the expression we seek. That expression is

$$SW_n = \frac{(a-\zeta)^2 n(2+n)}{2b((1+n)^2}. \blacksquare \tag{3}$$

We can use equations (1)-(3) to shed light on how the water pollution in the Ganges, generated as a byproduct of leather production, influences an arbitrary tannery's equilibrium output, price, profits, and social welfare. Looking at the coefficient of the total cost function $\zeta q$, we know that $\zeta = \alpha + \beta$. Now, all else being equal, suppose that there is an increase in water pollution in the Ganges. Then this leads to a greater amount of required tannery waste treatment. In turn, this increase can be expected to raise the cost of this treatment or $\beta q$. This last effect can be captured by postulating a rise in the coefficient $\beta$. In symbols, $\beta \uparrow \Rightarrow \zeta \uparrow$.

Inspecting equation (1), we see that $\zeta \uparrow \Rightarrow q_n \downarrow$ and $\zeta \uparrow \Rightarrow Q_n \downarrow$. In other words, all else being equal, a rise in water pollution increases the total cost of producing leather and this reduces the per tannery and the industry equilibrium output of leather in our stylized Kanpur economy. Next, consider the equilibrium price of leather in equation (2). Inspecting this equation, it is clear that $\zeta \uparrow \Rightarrow P_n \uparrow$. Put differently, all else being equal, an increase in water pollution in the Ganges raises the equilibrium price received by the leather producing tanneries in our model. The reader should note that this is to be expected because we just ascertained that an increase in water pollution reduces the equilibrium output of leather.

Next, let us consider the impact of rising water pollution in the Ganges, which we proxy by increasing the value of the cost parameter $\zeta$, on tannery profits $\pi_n$ and social welfare $SW_n$. Our results are stated in

*Proposition 4.* In our model, $\partial\pi_n/\partial\zeta < 0$ and $\partial SW_n/\partial\zeta < 0$.

*Proof.* Partially differentiating the expression for $\pi_n$ in equation (2) with respect to the parameter $\zeta$, we get $\partial\pi_n/\partial\zeta = \{-2b(a-\zeta)(1+n)^2\}/\{b(1+n)^2\}^2 < 0$. Similarly, differentiating the expression for social welfare from equation (3) with respect to the parameter $\zeta$ gives us $\partial SW_n/\partial\zeta = \{-4bn(a-\zeta)(2+n)(1+n)^2\}/\{2b(1+n)^2\}^2 < 0$. Writing these two comparative statics results together, we get

$$\frac{\partial\pi_n}{\partial\zeta} = \frac{-2b(a-\zeta)(1+n)^2}{\{b(1+n)^2\}^2} < 0, \frac{\partial SW_n}{\partial\zeta} = \frac{-4bn(a-\zeta)(2+n)(1+n)^2}{\{2b(1+n)^2\}^2} < 0. \blacksquare \qquad (4)$$

The denominator on the RHS of the ratio expression for $\partial\pi_n/\partial\zeta$ in equation (4) is clearly positive and the numerator is negative because $(a-\zeta)>0$ by assumption. This tells us that an increase in water pollution in the Ganges leads to a decline in the profits of the individual tanneries under study. Next, consider the impact of a rise in water pollution on social welfare in our stylized Kanpur economy. Inspecting the RHS of the ratio expression for $\partial SW_n/\partial\zeta$ in equation (4) we see that as in the case of individual tannery profits, the denominator is clearly positive and the numerator is, once again, negative because $(a-\zeta)>0$. In other words, rising water pollution in the Ganges is not just bad for the profits of the individual tanneries but it also reduces social welfare in our stylized Kanpur economy. Our next task is to analyze, from a profit perspective, whether it makes sense for a regulator to require $m<n$ tanneries to unitize or merge.

## 3. The Unitized Entity

Given that $m<n$ tanneries are required to unitize, with a view to reducing water pollution in the Ganges, a key issue that we need to address is whether this unitization is profitable for the unitized tanneries. In other words, this unitization is profitable if and only if the profits after unitization or $\pi_{n-m+1}$ exceed the pre-unitization profits given by $m\pi_n$. In symbols, we can write this condition as

$$\frac{(a-\zeta)^2}{b(n-m+2)^2} > m\frac{(a-\zeta)^2}{b(1+n)^2}. \tag{5}$$

Canceling the $b$ term from both sides of the inequality in (5), then dividing the two sides by $(a-\zeta)^2$ gives us

$$\tfrac{1}{(n-m+2)^2} - \tfrac{m}{(1+n)^2} > 0. \tag{6}$$

The expression on the left-hand-side (LHS) of (6) can be factored. This gives us

$$\left(\tfrac{1}{n-m+2} - \tfrac{\sqrt{m}}{1+n}\right)\left(\tfrac{1}{n-m+2} + \tfrac{\sqrt{m}}{1+n}\right) > 0. \tag{7}$$

Now, to make further progress, observe that the second term in the product on the LHS of (7) is always positive. Therefore, using this fact, the inequality on the LHS of (7) is satisfied as long as

$$\tfrac{1}{n-m+2} - \tfrac{\sqrt{m}}{1+n} \geq 0. \tag{8}$$

The above expression on the LHS of (8) can be written as

$$\tfrac{1+n-\sqrt{m}(n-m+2)}{(1+n)(n-m+2)} \geq 0. \tag{9}$$

The denominator of the fraction on the LHS of (9) is clearly positive. So, for the inequality in (9) to hold, we need

$$1 + n - \sqrt{m}(n-m+2) \geq 0. \tag{10}$$

Let us now solve the inequality in (10) for $n$ and then simplify the resulting expression. This gives us

$$n \geq \tfrac{1-(2-m)\sqrt{m}}{\sqrt{m}-1}. \tag{11}$$

Our next goal is to rewrite and then simplify the expression on the RHS of the inequality in (11) so that we can interpret the resulting expression in a straightforward manner. We get

$$\frac{1-(2-m)\sqrt{m}}{\sqrt{m}-1} = \frac{1-(2-m)(\sqrt{m}-1)-(2-m)}{\sqrt{m}-1} = \frac{(m-1)-(2-m)(\sqrt{m}-1)}{\sqrt{m}-1}. \tag{12}$$

The last fraction in equation (12) can be simplified further. This simplification yields

$$\frac{(m-1)-(2-m)(\sqrt{m}-1)}{\sqrt{m}-1} = \frac{(\sqrt{m}-1)(\sqrt{m}+1)-(2-m)(\sqrt{m}-1)}{\sqrt{m}-1} = \sqrt{m}-1+m. \tag{13}$$

The function on the RHS of equation (13) is clearly a non-linear function of the number of merging firms or $m$. Therefore, from a practical standpoint, we would like to have a "rule of thumb function" that well approximates this non-linear function. Numerical analysis shows that for small to moderately large $m$ and $m \geq 2$, the non-linear function $\sqrt{m}-1+m$ can be approximated well by a straight line with slope 0.8.

A second way to obtain this same finding is as follows. Suppose that before unitization, all the $n$ tanneries are very similar to each other. Then, the pre-unitization leather market share of each individual tannery is $s = 1/n$. After unitization, the leather market share of the unitized entity is $s = m/n$. For this unitization to be profitable, from equation (5), we need the condition $(1+n)^2 \geq m(n-m+2)^2$ to hold. Solving numerically, as $n$ grows, but not without bound, the smallest market share $s$ for which the preceding inequality holds is $s \geq 0.8$.

Two points now deserve additional commentary. First, observe that the $m \geq 2$ stipulation made above is without loss of generality because the smallest possible merger involves setting $m = 2$. Second, given the reasoning in the preceding two paragraphs, the inequality $n \geq \sqrt{m} - 1 + m$ can be called a *80 percent rule*. This means that the unitization under study in this section is profitable if and only if the pre-unitized tanneries together have a leather market share of at least 80 percent. Put differently, if the goal of a regulator is to reduce water pollution in the Ganges by requiring the polluting tanneries to unitize then this unitization makes sense from a commercial or profitability standpoint if and only if the combined leather market share of the relevant tanneries before they are unitized is at least 80 percent. We now study the impact of this unitization on the remaining $(n - m)$ tanneries that are not unitized.

## 4. The Non-Unitized Tanneries

We begin by stating the basic result of this section as

*Proposition 5.* Each of the non-unitized tanneries is better off from a profit standpoint with the $m$-tannery unitization.

*Proof.* Inspecting equation (2), we see that the profits of an arbitrary tannery in our stylized Kanpur economy or $\pi_n$ is a decreasing function of the total number of industry tanneries or $n$. So, $n \uparrow \Rightarrow \pi_n \downarrow$. Using this last result in equation (5), we reason that because

$(n-m+2)^2 < (1+n)^2$, it follows that $\pi_{n-m+1} > \pi_n$. Writing this last inequality in full, with the appropriate substitutions, we get

$$\frac{(a-\zeta)^2}{b(n-m+2)^2} = \pi_{n-m+1} > \pi_n = \frac{(a-\zeta)^2}{b(1+n)^2}. \blacksquare \tag{14}$$

The inequality in (14) clearly tells us that each of the non-unitized tanneries is *better off* from a profit standpoint with the $m$-tannery unitization and therefore we can expect these tanneries to lobby the regulator for unitization. Our last task in this paper is to demonstrate that the $m$-tannery unitization increases the industry price of leather and lowers social welfare.

## 5. Unitization and Social Welfare

We begin by noting that we have already established two specific results in equation (4) in section 2. First, an increase in water pollution in the Ganges leads to a decline in the profits of the individual tanneries. Second, rising water pollution in the Ganges reduces social welfare in the stylized Kanpur economy. Our objective now is to analyze the impact of unitization on the industry price of leather and on social welfare. To this end, we state our basic result in

*Proposition 6*. The $m$-tannery unitization increases the equilibrium industry price and it reduces social welfare in our stylized Kanpur economy.

*Proof*. Partially differentiating the expression for $P_n$ in equation (2), we see that the industry price $P_n$ is decreasing in the total number of tanneries $n$ or $n \uparrow \Rightarrow P_n \downarrow$. Hence, the $m$-tannery unitization clearly raises the equilibrium price $P_n$ and our claim follows. Next, differentiating the expression for social welfare in equation (3) with respect to the number of tanneries in our leather manufacturing industry or $n$, we see that social welfare is an increasing function of $n$ or $n \uparrow \Rightarrow SW_n \uparrow$. This last finding tells us that

$$SW_{n-m+1} \leq SW_n, \tag{15}$$

and our claim about the $m$-tannery unitization reducing social welfare follows. $\blacksquare$

## 6. Policy Implications

We have just shown that the $m$-tannery unitization *attenuates* social welfare in our stylized Kanpur economy. A key lesson from our analysis thus far is that unless there are extra efficiency gains from a $m$-tannery unitization, this kind of unitization *cannot* enhance social welfare and, in addition, it can be profitable only when the number of unitized tanneries or $m$ is "very large." As the detailed analysis in section 3 shows, "very large" means that the pre-unitized tanneries must have a leather market share of at least 80 percent.

How do these findings square with the Batabyal (2023) and Batabyal *et al.* (2023) claim about unitization likely leading to a decline in water pollution in the Ganges in Kanpur? To find out, let us assume, as these two studies implicitly do, that water quality (water pollution) in the Ganges is an increasing (decreasing) function of the number of unitized tanneries or $m$ in Kanpur. This means that as the unitized entity becomes large, water quality in the Ganges improves or, put differently, water pollution declines. If this assumption is valid then regulators have an incentive to create a large, unitized entity because such an action can be justified on profitability grounds because it increases the profits of both the unitized and the non-unitized tanneries *and* on environmental grounds because it lowers water pollution in the river under consideration. However, the downside of such a course of action is that it raises the industry price of leather and reduces social welfare in our stylized Kanpur economy.

If the above assumption is invalid, then profitability and environmental considerations are in *conflict*. In particular, profitability considerations alone suggest that a regulator create a large, unitized entity but environmental considerations would suggest that this regulator not engage in unitization. This completes our discussion of tanneries in Kanpur, India, water pollution in the Ganges, and unitization.

## 7. Conclusions

In this paper, we theoretically analyzed the merits of a claim made recently in the literature that unitizing the polluting tanneries can improve water quality in the Ganges in the vicinity of Kanpur, India. We first described the $n \geq 2$ polluting tanneries as a Cournot oligopoly and derived the equilibrium output of leather, price, profits, and social welfare. Second, we required $m < n$ tanneries to merge and determined when this $m$-tannery unitization was profitable for the unitized entity. Third, we showed that the $(n -$

$m$) non-unitized tanneries were better off with unitization. Finally, we demonstrated that the $m$-tannery unitization raised the industry price of leather, lowered social welfare, and then we discussed the repercussions of our findings for improved water quality in the Ganges.

The analysis in this paper can be extended in several ways. Here are two examples. First, it would be useful to see how the results of this paper compare with the results obtained from an alternate model in which the total cost of producing leather by the various tanneries depends not just on variable costs but also on fixed costs. Second, it would be instructive to analyze the questions studied in this paper in a dynamic setting in which tanneries enter and exit the leather manufacturing industry in Kanpur to determine how entry and exit affect the usefulness of unitization in such an intertemporal setting. Studies that analyze these aspects of the underlying problem will provide further insights into the ways in which unitization can influence water quality in the Ganges and the livelihoods of the many individuals who live in and around the city of Kanpur in India.

References

Arya, S., and Gupta, R. 2013. Water quality evaluation of Ganga river from up to downstream area at Kanpur city, *Journal of Chemistry and Chemical Sciences*, 3, 54-63.

Batabyal, A.A. 2023. Tanneries in Kanpur and pollution in the Ganges: A theoretical analysis, *Regional Science Policy and Practice*, 15, 1114-1124.

Batabyal, A.A., Kourtit, K., and Nijkamp, P. 2023. Climate change and river water pollution: An application to the Ganges in Kanpur, *Natural Resource Modeling*, 36, e12370.

Chakraborty, P., and Chakraborty, D. 2007. Environmental regulations and Indian leather industry, *Economic and Political Weekly*, 42, 12-18.

Chaudhary, M., and Walker, T.R. 2019. River Ganga pollution: Causes and failed management plans (correspondence on Dwivedi et al. 2018. Ganga water pollution: A potential health threat to inhabitants of Ganga basin. Environment International 117, 327–338), *Environment International*, 126, 202-206.

Das, P., and Tamminga, K.R. 2012. The Ganges and the GAP: An assessment of efforts to clean a sacred river, *Sustainability*, 4, 1647-1668.

Hartwick, J.M., and Olewiler, N.D. 1998. *The Economics of Natural Resource Use*, 2nd edition. Addison-Wesley, Reading, MA.

Ingle, K.N., Harada, K., Wei, C.N., Minamoto, K., and Ueda, A. 2011. Policy framework for formulating environmental management strategy for sustainable development of tanneries in India, *Environmental Health and Preventive Medicine*, 16, 123-128.

Ioan, G., and Iona, C.A. 2015. The Cournot equilibrium for *n* firms, *European Integration Realities and Perspectives Conference Proceedings*, https://www.researchgate.net/publication/275945749_The_Cournot_Equilibrium_for_n_Firms?channel=doi&linkId=5549cb930cf205bce7ac3fcd&showFulltext=true. Accessed on 11 April 2025.

Khwaja, A.R., Singh, R., and Tandon, S.N. 2001. Monitoring of Ganga water and sediments vis-a-vis tannery pollution at Kanpur (India): A case study, *Environmental Monitoring and Assessment*, 68, 19-35.

Mallet, V. 2017. *River of Life, River of Death*. Oxford University Press, Oxford, UK.

Markandya, A., and Murty, M.N. 2004. Cost–benefit analysis of cleaning the Ganges: Some emerging environment and development issues, *Environment and Development Economics*, 9, 61-81.

McBride, P. 2014. Industry on the banks: Deep inside Kanpur's tanneries, *National Geographic*, August 6, https://www.nationalgeographic.com/photography/article/industry-on-the-banks-deep-inside-kanpurs-tanneries. Accessed on 11 April 2025.

Salant, S.W., Switzer, S., and Reynolds, R.J. 1983. Losses from horizontal merger: The effect of an exogenous change in industry structure on Cournot-Nash equilibrium, *Quarterly Journal of Economics*, 98, 185-199.

Singh, A., and Gundimeda, H. 2021. Measuring technical efficiency and shadow price of water pollutants for the leather industry in India: a directional distance function approach, *Journal of Regulatory Economics*, 59, 71-93.

Singh, A.P., and Rao, D.P. 2013. Assessment of tannery effluent: A case study of Kanpur in India, *European Chemical Bulletin*, 2, 461-464.

Tirole, J. 1988. *The Theory of Industrial Organization*. MIT Press, Cambridge, MA.