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Long-term changes in wastewater reuse and health, a case study in Kanpur, India

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Long term changes in wastewater reuse and health, a case study in Kanpur, India

Master of Science Thesis

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Abstract

Kanpur is facing significant challenges in managing wastewater. These challenges are due to the inadequacy of the wastewater treatment plants (WWTP), poor compliance with wastewater discharge standards, and illegal discharge of effluent from tanneries into the Jajmau sewerage treatment plants (STP). Six STPs exist in Kanpur, three in Jajmau, and all receive illegal discharge of tannery effluent. Despite not meeting the reuse standards, the combined effluent is discharged and used for irrigation via a reuse scheme in 40 nearby villages covering about 2,000 hectares.

This research explored the historical relationship between wastewater reuse and health in villages surrounding Jajmau STP. The study used a mixed method approach by engaging in in-depth life histories with the farmers and key informant interviews (KII) with the experts. It focused on two villages in a life history case-control study. Alaulapur is a case village that uses wastewater for its irrigation scheme, and Lalukheda is a control village that uses groundwater for its irrigation scheme. The research compared historical themes for the schemes on irrigation practices, farming practices, and changes in the health of the farmers and their families.

The wastewater reuse scheme in the villages along Jajmau STP was in place before the construction of the first STP in 1989. The municipality supports this scheme by maintaining the channels that allow farmers to access the combined irrigation wastewater in the villages.

Although the villages share similar characteristics, their farming practices have evolved, with the irrigation scheme being the driving factor. In Alaulapur, from 1995 to date, there have been major problems with skin, lung, and cancerous conditions, indicating a potential correlation with exposure to chemical contamination of heavy metals such as chromium over time. In contrast, Lalukheda has faced mild health developments.

Due to irrigation wastewater, Alaulapur can only grow millet, rice, and wheat. This shift in agriculture has potentially affected the nutritional diversity of the village's diets and the health of farmers and their families. However, Lalukheda’s economic growth has improved health since the 2010s and is attributed to crop diversity and sufficient food supply.

Alaulapur village crops are irrigated through flooding, which has caused problems with direct and indirect exposure, resulting in farmers' exposure to Escherichia coli (E. coli) and chromium contaminants. It has also contributed significantly to methane (CH4) production, resulting in greenhouse gas (GHG) emissions in the environment. On the other hand, Lalukheda village adopted more Morden irrigation practices that focused on cost efficiency and technological advancement. Over time, both villages' farming practices shifted from using traditional animal-driven ploughs to tractors, driven by the need for efficiency and cost savings. Lalukheda uses fertiliser, while Alaulapur does not.

To ensure the long-term effects of wastewater on the environment and end-users are minimised, measures must be taken to restrict the inappropriate disposal of tannery effluent and ensure the regulation of standards for treating industrial and municipal effluent. Additionally, proper policies on the reuse of wastewater should be formulated to avoid long-term effects.

Keywords: Wastewater treatment plants, case-control study, contamination, nutrition diversity, irrigation,

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Abbreviations

Cr	Chromium
CETP	Common Effluent Treatment Plant
CPHEEO	Central Public Health and Environmental Engineering Organisation
IITK	Indian Institute for Technology Kanpur
KMA	Kanpur Metropolitan Authority
KMC	Kanpur Municipal Council
KII	Key Informant Interview
MLD	Million Litre Per Day
OM	Organic Matter
SDG	Sustainable Development Goals
SFD	Shit Flow Diagram
STP	Sewerage Treatment Plant
UN	United Nations
WHO	World Health Organisation
WWTP	Waste Water Treatment Plant

Chapter 1 **Introduction**

This chapter will provide the background information on the research topic, state the research problem, outline the study objectives, and present questions to help address the problem.

1.1 Background

Water scarcity is an emerging global challenge caused by climate change, population growth, economic expansion, and dietary changes (Scheierling et al. 2010).

Wastewater from domestic households accounts for 50% to 80% of the total discharged volume into the environment (Hussain et al. 2019). Wastewater reuse depends on many factors, including the quantity of wastewater produced, the rising global need, climate change impact on water bodies, and the amount of wastewater discharged from households and manufacturing industries (Schellenberg et al. 2020b). In the global north, wastewater is used for recharging water aquifers and reduces transboundary water conflicts (Schellenberg et al. 2020a). Wastewater has been seen to reduce harmful greenhouse emissions via carbon storage and energy conservation (Shahabadi et al. 2009).

Wastewater includes vital nutrients like nitrogen and phosphorous for plant growth (Cordell et al. 2009). The growing scarcity of phosphorus, more so that 70% of water is drawn for agricultural use, makes wastewater an ideal resource for irrigation (Cordell et al. 2009). It further offers energy recovery opportunities and is essential in increasing food security and sustainable agriculture activities (Skoet and Stamoulis 2006; Hurdalkova et al. 2016). Treated wastewater with a measured level of nutrients has been found to decrease the use of more fertilisers in crop production (Smol et al. 2020). According to Lerner and Eakin (2011), it’s been observed that demand for agriculture products has created markets near effluent treatment plants where crops are grown using irrigation schemes.

India faces enormous water scarcity challenges, and its population is projected to surpass 1.5 billion by 2050 (Minhas and Samra 2004). This will trigger water use and the generation of large wastewater quantities (Minhas and Samra 2004). According to projections, 26.4km3 wastewater is produced annually, and only 28% is treated (Minhas et al. 2022). Untreated water is likely to irrigate 2.1 million hectares of agricultural areas (Minhas et al. 2022).

The sewerage treatment plants (STP) capacity in India is inadequate, leading to untreated discharges for irrigation use (Minhas et al. 2022). The Ganga Action Plan (GAP) indicates six sewage treatment plants were constructed in the Utter Pradesh city of Kanpur (Breitenmoser et al. 2022). According to Pavitra Ganga (2020), the discharges from these Sewage treatment plants (STP) are partially treated or do not entirely meet the reuse standards (Schellenberg et al. 2020a). This is treated or semi-treated wastewater is discharged into ordinary drains connecting to water bodies or reused for irrigation (Minhas et al. 2022). STPs must be capable of treating effluent to desired levels to protect public health and enforce regulation (Talebizadeh et al. 2014). To make wastewater ideal for irrigation and to protect health, discharge wastewater must achieve a minimum quality standard that contains safe but attainable levels of pathogens, heavy metals and other organic micropollutants (WHO 2006). India's national water policy for 2012 promotes reusing to the specified standard (Minhas et al. 2022).

Several research studies have been conducted on wastewater reuse and health. Still, none has looked at the historical perspective of wastewater reuse on the farmers, their families and the consumers.

1.2 Research problem

Kanpur, an industrial city in India, is struggling to manage wastewater due to the illegal discharge of fluent from the tanneries into the Jajmau wastewater treatment Plant (WWTP) (Pavitra Ganga 2020; Breitenmoser et al. 2022). Inadequate number of STPS and lack of adherence to effluent discharge standards are among the other challenges (Pavitra Ganga 2020; Babalola et al. 2023; Pavitra Ganga "n.d"). Six STPs exist in Kanpur Metropolitan, three of which are in Jajmau area (Pavitra Ganga 2020). An Up-flow Anaerobic Sludge blanket STP that treats 5 MLD, a CETP with 30MLD capacity designed for combined tannery and domestic wastewater and an STP for domestic wastewater with 130 MLD, still all these three receive tannery effluent (Pavitra Ganga 2020).

The combined effluent is discharged into the drainage channels and is used in a wastewater reuse scheme for irrigation even though it does not meet the Indian wastewater reuse standards (Pavitra Ganga 2020; Schellenberg et al. 2020b). 40 villages down the Jajmau STP and CETP use the effluent for farm irrigation (Breitenmoser et al. 2022). According to baseline survey data, about 2000 hectares of land is irrigated downstream of the Jajmau STP/CETP for rice and wheat growing (Pavitra Ganga "n.d").

There’s limited historical information about the historical development of the wastewater reuse scheme, changes in irrigation practice farming practices and the changes in the health of the farmers and their families over time.

Studies have explored the “effects of emerging technology on occupational health and community health risk associated with wastewater treatment and irrigation reuse” (Babalola et al. 2023). These studies have focused on risk assessment, treatment options, effluent reuse and adherence to standards (Pavitra Ganga 2020). Other studies have been conducted to “assess the effectiveness of risk communication in addressing health concerns among farmers and health care workers” (Breitenmoser et al. 2022; Babalola et al. 2023).

This study will encompass a comprehensive investigation of the irrigation reuse scheme history, practices and health outcomes related to wastewater reuse in the Jajmau village and the groundwater irrigation scheme village, focusing on both irrigation and farming practices, as well as their impact on the health of the local population. This study will positively impact agriculture practices profile, public health and policy development in the Jajmau area and potentially serve as a model for similar sites.

1.2.1 Research aim

This research aims to explore the historical relationship between wastewater reuse and health in villages surrounding Jajmau municipal wastewater treatment plant in Kanpur, India.

1.2.2 Research objectives and questions

1.2.2.1 Research Questions

1. How do farming practices differ between villagers who used effluent for irrigation and those which did not?
2. How did the health of farmers and their families differ between villages which used effluent for irrigation and those that did not?
3. How has the irrigation scheme impacted the health of farmers and their families?

1.2.2.2 Objectives

1. To review the history of the wastewater reuse schemes related to the Jajmau Sewerage Treatment Plant.
2. To investigate and compare historical changes in irrigation Practices in Alaulapur and Lalukheda.
3. To investigate and compare the historical changes in farming practices in villages that have used effluent for irrigation purposes with villages that have not from before the irrigation schemes until now.
4. To investigate and compare the health of the farmers and their families in villages that have used effluent for irrigation purposes with villages that have not, from before the irrigation schemes until now.
5. To explore the relationship between villagers' health and wastewater reuse from the Jajmau municipal wastewater treatment plant.

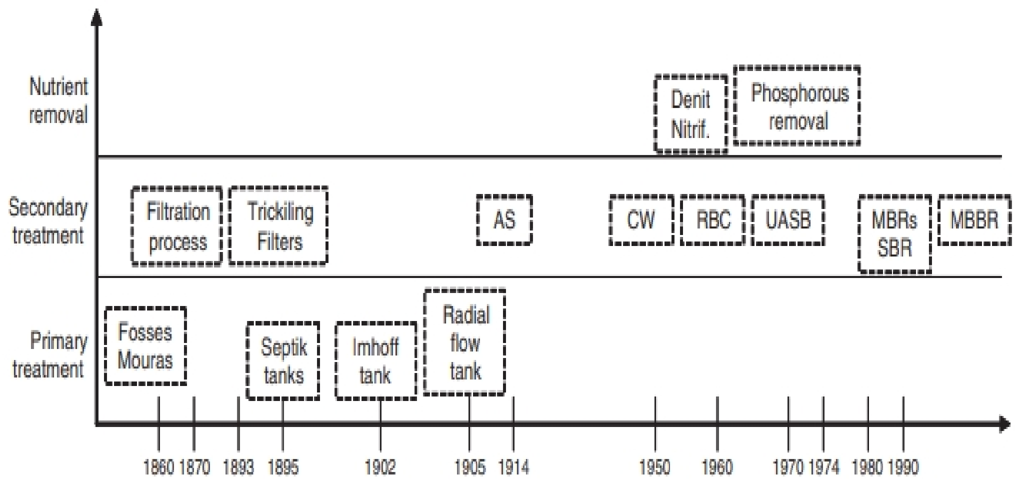
Chapter 2 **Literature Review**

2.1 **Wastewater treatment**

2.1.1 **History of wastewater treatment**

The main objective of wastewater treatment is to dispose of various types of waste, including human, commercial, and manufacturing, without causing any harm to humans and the environment (Drexler et al. 2014). According to Mcghee (1991), the evolution of wastewater treatment began in the 1900s, and since then, several treatment processes have been developed to standardise the output and ensure compliance (Topare et al. 2011). Initially, wastewater was treated through open space emptying or dispersion on bare ground (Topare et al. 2011). This led to land contamination and the spread of faecal-oral diseases when wastewater was discharged into water bodies such as rivers, lakes, and oceans (Topare et al. 2011).

Sludge and sewage application in India have been done since 1896 when it was first implemented in Ahmadabad, then Poona in 1918, and Madura in 1928 (Minhas and Samra 2004). Currently, over 300 wastewater farms exist that manage waste for local municipalities (Minhas and Samra 2004; Minhas et al. 2022).



. Evolution of wastewater treatment. AS - Activated sludge; CW - constructed wetlands; RBC - Rotating biological reactors; UASB - Upward-flow anaerobic sludge blanket; - Membrane biological reactors, SBR - Sequencing Batch Reactors; MBBR - Moving Bed Biofilm Reactors.

Figure 1 Historical development of development of treatment plants (Lofrano and Brown 2010)

2.1.2 **Health and environmental impacts of untreated wastewater**

Increased amounts of total nitrogen in wastewater reduces crop yield because of lodging, this happens for crops like rice, and it leads to the motivation of growth in algae and bacteria (Setter et al. 1997; Schellenberg et al. 2020a). Industrial wastewater contains different organic elements like pharmaceuticals, chemicals, insecticides and heavy metals such as lead and chromium, which can accumulate in soil and plants and cause harm to people (Gupta and Gupta 1998). equally unnecessary quantities of trace elements cause damage to crops and lessen yield (Asano et al. 2007; Schellenberg et al. 2020b). According to research on contamination with two divergent views, “food crops and roots accumulate fewer heavy metals, while leafy vegetables accumulate more” (Qureshi et al. 2016; Mishra et al. 2023). “Heavy metals tend to accumulate more in the roots of plants than in other edible parts or leaves” (Parveen et al. 2015). Cherfi et al. (2015) say food contaminated with heavy metals causes ailments of the nervous system, immune system and even cancer.

Total organic carbon (TOC), BOD, and chemical oxygen demand(COD) are indicators used to recognise the concentration of organic matter (OM) in water, breakdown of OM can lead to a reduction of oxygen, critical for other organisms in water (Asano et al. 2007).

Transmission of feacal oral diseases occurs through several pathways, with contact and consumption being the most critical (see Figure 2) (Sphere Association 2018). Direct contact with irrigation wastewater while farming or playing near open channels poses health risks (Babalola et al. 2023). According to Beuchat and Ryu (1997), Farmers, their children and those who consume their crops are at risk of exposure to contamination threats such as odours, skin infections, toxicity and several pathogenic infections. Failure to control these pathways can spread fecal oral diseases like cholera, dysentery, typhoid, and shigellosis (see Figure 3) (WHO 2021). Therefore, proper sanitation practices are necessary to act as a primary barrier and prevent the transmission of these diseases (figure 2). F. Diagram illustrates the transmission routes and possible barriers to stopping the transmission of pathogens from the feaces of one infected person to another (McMahon and Shaw 2019; SFD 2020).

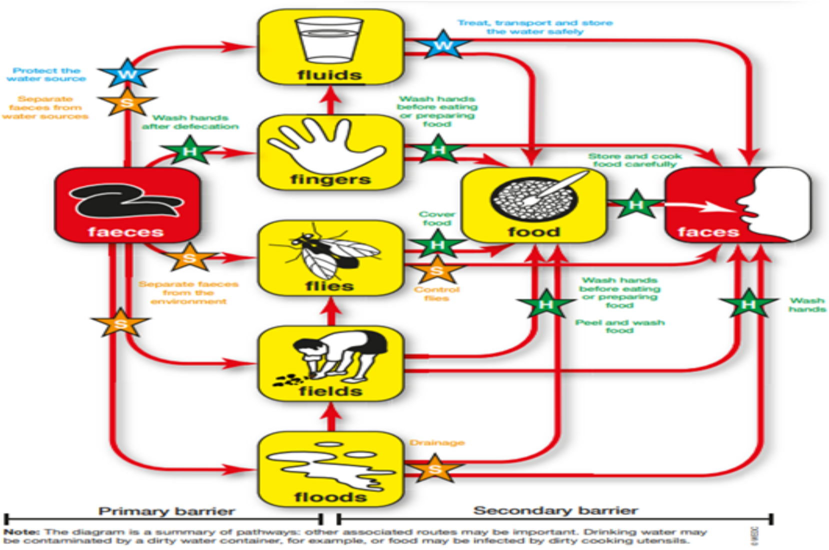


Figure 2 Shit flow diagram, source: (McMahon and Shaw 2019)

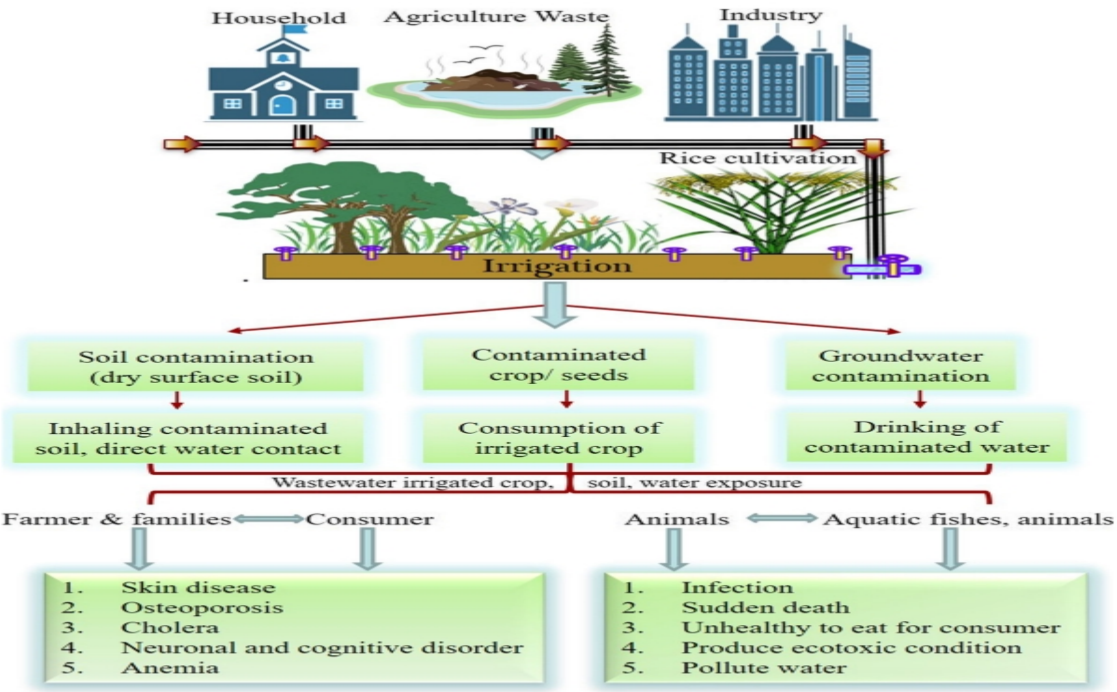


Figure 3 “Exposure pathway from wastewater-irrigated crops” (Kesari et al. 2021b)

2.1.3 Treatment process

The composition of wastewater can vary depending on its sources. Four main treatment stages continue to evolve in wastewater treatment (Drexler et al. 2014).

During the preliminary treatment stage, physical or mechanical processes are utilised to separate large contaminants from the wastewater using screens (Feachem et al. 1983; Topare et al. 2011), In the subsequent primary treatment stage, various techniques are employed to eliminate solid particles and biological matter that settle through gravity, as well as lighter particles that are suspended in the wastewater (Mcghee 1991). Drexler et al. (2014) describe the primary wastewater process aims to produce a clear effluent that can be discharged as effluent while returning solid particles as sludge for further treatment.

The "secondary treatment" process involves using bacteria to break down organic matter in wastewater, resulting in a clear effluent with 85% of organic matter removed (Topare et al. 2011). According to Metcalf et al. (1991), various techniques such as reactors, aeration tanks, settling tanks, trickling filters, and oxidation ponds are employed to treat wastewater by decomposing biological matter and floating objects through aerobic and anaerobic digestion.

The advanced or tertiary treatment system is a polishing or purification stage that removes nitrogen, phosphorus, suspended solids, heavy metals, and dissolved solids from the effluent to ensure safe discharge (Topare et al. 2011). According to Drexler et al. (2014), various technologies area used, such as osmosis, chemical coagulation, and flocculation, before discharging into the environment or river. The process removes all impurities that hinder wastewater reuse (Prabu et al. 2011).

2.2 Reuse of effluent from wastewater treatment

2.2.1 Why reuse effluent

The depletion of freshwater sources is a major concern, which is why reusing effluent has become more common. Effluent is suitable for various purposes such as landscaping, irrigation, flushing toilets, and recharging groundwater (Minhas et al. 2022). This can significantly reduce the pressure on freshwater sources, and with the changing climate, there is a growing need for wastewater reuse for specific applications, especially in agriculture (Angelakis and Bontoux 2001; Pedrero et al. 2010).

According to Schellenberg et al. (2020a), the choice to reuse effluent hinges on the amount of wastewater produced, the increasing global demand for water, the effect of climate change on river water, and the bulk of sewage discharged from households and industries, wastewater is good to recharge aquifers. It reduces transboundary conflicts on water (Schellenberg et al. 2020a).

Wastewater contains valuable nutrients such as Nitrogen and Phosphorus, which are essential for plant growth. Additionally, it provides a chance for energy retrieval (Cordell et al. 2009). The increasing scarcity of phosphorus (a plant macronutrient that plays a vital role in food security) and the fact that 70% of total water withdrawal is for agricultural use make wastewater an attractive resource for irrigation (Cordell et al. 2009).

2.2.2 Main uses of effluent in agriculture

The world uses more water for food production, about 92% (Rost et al. 2008; Kesari et al. 2021a). Treated effluent discharged from STP can be reused for beneficial activities (Gutterres and de Aquim 2012; Shoushtarian and Negahban-Azar 2020). This practice of reusing wastewater has been present for a long time with the Greeks among the pioneers to use buckets for storage of night soil and later excreta for agricultural fields (Angelakis et al. 2018).

According to Qadir et al. (2007), many countries rely on wastewater reuse to sustain agriculture and increase food availability. According to Okem and Odindo (2020) use of effluent in agriculture has been found to produce great yields due to its nutrient rich content, and that its cheap as it's an alternative to fertilizers (Schellenberg et al. 2020a).

However, the study noted that the scale of expansion of effluent use is limited, primarily due to a lack of information. This lack of knowledge has resulted in a challenging social acceptance of crop products (Okem and Odindo 2020).

Lerner and Eakin (2011) emphasise that demand for agricultural products has led to the creation of markets near effluent treatment plants, where crops are grown using these schemes. However, despite various innovations in reuse, there are still some grey areas that need to be resolved such as people's perception, health and how regulations can be handled (Rice et al. 2016; Massoud et al. 2018).

2.2.3 The controls for the reuse of effluent in agriculture

Blumenthal and Peasey (2002) reported that the World Health Organisation (WHO) established regulatory standards for the safe use of treated effluent in 1973, which were later revised in 1989. Additional guidelines were developed based on subsequent research in microbiology (Schellenberg et al. 2020b; Shende and Pophali 2022). Emerging evidence-based health concerns prompted global institutions to revise their guidelines in 2012. As a result, the WHO and other institutions have created updated regulations (Jaramillo and Restrepo 2017; Schellenberg et al. 2020b).

Schellenberg et al. (2020b) discuss the categorisation of reuse based on the value of the produce, irrigation system, and water purification, which has led to more efficient implementation of standards. Disease-causing agents like E. coli, BOD, and TSS vary from country to country (Schellenberg et al. 2020a) and are among the indicators that need to be monitored (see Table 2). However, some countries have challenged this approach due to high wastewater reuse costs, concerns about human health risks, and inadequate coordination of regulatory principles for managing environmental and health risks (Sánchez-Cerdà et al. 2020; Truchado et al. 2021).

Table 2 Uniform procedures for treated effluent reuse (WHO 2006).

Category	Reuse condition for	Exposure group	Irrigation technique	Average E. coli/100mL	Log_{10} CFU/100mL
Unrestricted irrigation					
A	Vegetable and salad crops, eaten uncooked	Workers, Consumers Public	Any	$\leq 10^3$	≤ 3
Restricted irrigation					
B	Labour intensive farming practices for crops usually cooked, such as cereal crops	Workers, Nearby communities	Spray or sprinkler	$\leq 10^4$	≤ 4
		Workers, Nearby communities	Flood/furrow	$\leq 10^3$	≤ 3
C	Localized irrigation of crops in category B if exposure of workers and public does not occur, i.e. highly mechanized farming practices	None	Trickle, drip or bubbler	Not applicable	

2.3 Wastewater reuse for farming in India

2.3.1 Current status of wastewater

India's population was 1.34 billion in 2018 and is projected to reach 1.6-2 billion by 2030-2050 (Kaur et al. 2012). According to a recent study by Minhas et al. (2022), many towns in India release between 50-80% of their untreated effluent into the environment or water bodies. The study found that effluent from 118 towns goes directly into water bodies, and 63 municipalities use wastewater to irrigate farming land. This highlights a major issue with pollution and inadequate waste management in India. Many of India's urban areas, which are situated near rivers, are anticipated to discharge more wastewater than their treatment capacity can handle (Kaur et al. 2012). These areas are projected to discharge 38354MLD, while their treatment capacity is only 11786MLD (Kaur et al. 2012; Mukherjee et al. 2015). The BOD data stretches at various with levels from 1 to 5 stretching from a BOD value greater than 30mg/l, which is termed priority to BOD values between 3.1 and 6mg/l are priority 5 (Koshy 2018). Some of the common technologies used for wastewater treatment are the activated sludge process, up-flow anaerobic sludge blanket, and waste stabilisation ponds (Kumar and Tortajada 2020;

Shende and Pophali 2022). The majority of waste treatment systems use waste stabilisation ponds, followed by UASBs and STPs (Kumar and Tortajada 2020).

2.3.2 Changes in farming practices in India

India's Green Revolution from 1960 offered change for most agricultural developments, ranging from crops to animals, irrigation mechanisation and the use of chemicals to aid crop growth (Gulati and Juneja 2020b). The Green Revolution, a combination of the introduction of high-yielding seed varieties, increased use of fertilisers and irrigation, helped to enhance food grain production significantly (chakravarti 1973). India shifted from traditional to mechanised agriculture processes between the mid-20th century (1945 to 1975) and 2013-14. During this period, India introduced high-yielding crop varieties for wheat and rice, which increased demand for irrigation (Gulati and Juneja 2020a).

Farmers realised traditional water lifts couldn't meet the demand for new yielding grain varieties. Thus, the extensive rollout of diesel and electrical submissive pumps and drilling of boreholes and machinery such as tractors (Gulati and Juneja 2020a). After the total delicensing of tractor manufacturing in 1991, production and competition in the industry increased (Gautam et al. 2023). The Green Revolution increased food production and productivity in India, leading to higher agricultural incomes and demand for a more mechanised system (chakravarti 1973).

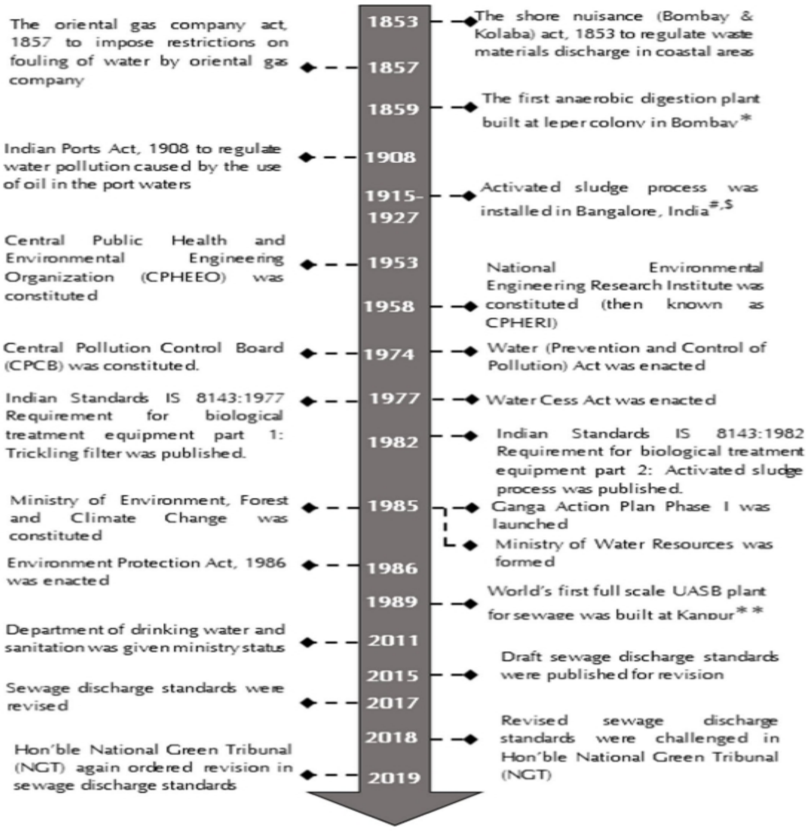
2.3.3 Historical perspective of farming methods and crops

India has a rich history of using wastewater in agriculture, with evolving methods and crops being applied for over 30 years (Minhas et al. 2022). The country has achieved agricultural sustainability and improved crop production by utilising irrigation water for farming areas (Kaur et al. 2012). According to Strauss and Blumenthal (1990), this was done to recover soil richness using various methods of wastewater application, such as direct application to plant roots and spreading on land to provide even coverage of wastewater underneath the subsoil. Additionally, Kaur et al. (2012) emphasised that this was a way to avoid contaminating the edible parts of the plants. Crop contamination can be minimised by using subsurface dripping for irrigation than through sprinklers or furrows; this reduces wastewater microbial pollution caused by irrigation practices and wastewater quality (Jiménez 2006).

According to Narayanamoorthy (2006), drip and surface irrigation methods have been used and can minimise health hazards for farmers, particularly when cultivating non-edible plants for beautification purposes. However, this method has its limitations, and research suggests the installation of filtration settling tanks at the farm level for water cleaning before use (Gupta et al. 2016). Bradford et al. (2003) state that this method was initially developed and used to supply wastewater intermittently from a dug trench. However, with screens to remove large particles, it is now considered a breakthrough in supporting local processes. In India, wastewater irrigation is widely used to handle large volumes of wastewater (see Figure two on uniform procedures according to WHO for choice of irrigation method. (Bradford et al. 2003; Minhas et al. 2022).

2.3.4 **Historical overview of wastewater regulations and standards**

Figure 4 The change and application of regulations (Shende and Pophali 2022).



The formation of the Central Public Health and Environmental Engineering Organisation (CPHEEO) (in Figure 4)

in 1953 led to the implementation of regulations for effluent reuse (Shende and Pophali 2022). In 1974, a significant milestone was achieved, as shown (in Fig 4). The Act for securing water sources and managing wastewater was formed, creating central and state control boards as primary authorities to provide oversight (Schellenberg et al., 2020b). This marked the realisation of regulation.

According to Shende and Pophali (2022), the national urban sanitation policy was launched in 2008 to promote the safe storage of human waste, thus achieving 100% sanitation. The policy looked at the state of sanitation strategies and town plans as priority focus. In 2013, the national policy on feacal sludge and septage management was enacted (Shende and Pophali 2022).

In compliance with Indian regulations and standards, Table 3 outlines the wastewater standards that have been established to minimise the risk of potential infection with pathogenic microorganisms (Minhas et al. 2022). It is recommended to use only the wastewater that meets the standards outlined in the table for agricultural irrigation and other reuse purposes (CPHEEO 2013). According to the CPHEEO (2013) report, applying 11.0 to 28.0 kg/ha/day of organic loading (BOD5) is recommended to maintain a stable organic matter content in the soil. This will condition the soil with microorganisms and prevent clogging. According to Minhas et al. (2022), this will minimise eutrophication and aeration problems and minimise the toxic pollutants' entry into the food chain and the environment.

Table 3 Wastewater reuse standards for discharge over time (CPHEEO 2013; Minhas et al. 2022)

Wastewater reuse standards and it progression in India.

Parameters	CPHEEO, 2013[b]				MoEFCC, 2015[a]	MoEFCC, 2017		NGT, 2019[c]
	Horticulture	Raw edible crops	Cooked edible crops	Non-edible crops		Metro cities	Non-metro cities	
pH	6.5–8.3	6.5–8.3	6.5–8.3	6.5–8.3	6.5–9.0	–	6.5–9.0	5.5–9.0
BOD (mg L^{-1})	10	10	20	20	10	20	30	< 10
COD (mg L^{-1})	AA	AA	30	30	50	–	–	50
TN (mg L^{-1})	10	10	10	10	10	–	–	10
NH_4^+-N (mg L^{-1})	–	–	–	–	5.0	–	–	–
TP (mg L^{-1})	2.0	2.0	5.0	2.0	–	–	–	1.0
Coliform (MPN)[#]	NIL	NIL	230 FC[d]	230 FC	<100 FC		<1000 FC	<230 FC
TSS (mg L^{-1})	NIL	NIL	30	30	20	50	100	20
HE (eggs L^{-1})	<1.0	<1.0	<1.0	<1.0	–	–	–	–
Turbidity (NTU)	<2.0	<2.0	AA	AA	–	–	–	–
EC (dS m^{-1})	<2.1	<2.1	<2.1	<2.1	–	–	–	–

[a] MoEFCC: Ministry of Environment, Forest and Climate Change, Government of India (GOI).
[b] CPHEEO: Central Public Health & Environmental Engineering Organisation, Ministry of Housing and Urban Affairs, GOI.
[c] NGT: National Green Tribunal.
[d] FC: *Fecal coliform*; AA: as arising when other parameters are satisfied.
[#] MPN: most probable number in 100 ml.

2.3.5 **Health impacts from the reuse of effluent in farming India**

The most common contaminants in wastewater are microbes, heavy metals, and organic toxic compounds (Breitenmoser et al. 2022). Contaminants can enter crops through direct contact with irrigation water or absorption from soils, depending on environmental conditions and plant type, causing health problems for consumers and farm workers (Jiménez 2006). Oron et al. (1992) state that people are not informed about the transmission pathways of toxic chemicals from mixed effluent irrigation, which prevents them from understanding the long-term impact.

According to Bradford et al. (2003) among the many health outcomes of wastewater use included anaemia and skin infections, common in northern Karnataka due to poor diet and worm infections, also important is the contamination of potable water in the area with endosulfun an organochloride mostly found in combined irrigated areas, indicating groundwater pollution.

According to a study by Gupta et al. (2009), helminth contamination was observed in Titagarh metropolitan, suggesting soils irrigated with untreated effluent had 83%, 68% treated and vegetables 44%. Further, hookworm and round warm infections were considerably high among farm workers (Gupta et al. 2009). In another research done in Hyderabad, a high rate of illness was recorded among residents using wastewater for irrigation, and they experienced high expenses on disease compared to the others using groundwater (Srinivasan and Reddy 2009).

Chapter 3 **Research Methodology**

3.1 Study background

This case study forms part of a larger initiative of the Pavitra Ganga project in Kanpur, India. It’s a bilateral collaboration between the Indian government and the European Union (Pavitra Ganga 2020; Breitenmoser et al. 2022). The focus is to develop and trial innovations for wastewater treatment and reuse while also applying policy resolutions to resolve prevailing limitations and encourage extensive adoption of circular economy ideologies of “resource recovery” in India, in line with sustainable development goal number 6, ensuring availability and sustainable management of water and sanitation for all (Sadoff et al. 2020). The project aims to “unlock wastewater treatment, water reuse and resource recovery opportunities for urban and peri-urban areas in India”. The overall goal is to offer sustainable answers for wastewater treatment and reuse in India, emphasising and encouraging water quality while also working towards rejuvenating the Ganges River (Pavitra Ganga 2020).

3.2 Case study area

Located on the south shore of the main Ganga river, Kanpur is an urban town subject to rapid population growth, the current population is 3234000, a 1.38% growth from 2022 (United Nations 2018; Zarocostas 2022). A land area of 340km2 (Srinivasan and Reddy 2009). It is located geographically at 26.44°N and 80.33°E (Bassi and Kumar 2012). Kanpur is well known for its textile manufacturing industries, which have significantly contributed to the town's economic growth. However, these industries release large amounts of effluent into the environment which ultimately mixes with wastewater and is used in agriculture (Singh 2001; Breitenmoser et al. 2022). Currently, 16000 tannery industries discharge effluent into STPs (Pavitra Ganga 2020).

Kanpur experiences three favourable weather patterns every year, with varying seasonal climatic conditions. The hot season ranges from 30°c to 40°C, while lows of 4°c to 8°c accompany winter (Srinivasan and Reddy 2009). The town receives an average rainfall of around 800 mm from June to September (Srinivasan and Reddy, 2009).

Drinking water supply is surface water and groundwater sourced, supplied through a pipe network established in 1892 (Kanpur Nagar Nigam 2006). The Ganga river supplies 390MLD, but only 255MLD goes through the treatment process, while the treatment plant capacity is designed for 600MLD, an extra 130MLD of groundwater is also supplied but not treated (Srinivasan and Reddy 2009). Kanpur metropolitan area (KMA) has 6 STPs,3 in Jajmau. Jajmau is a suburb of Kanpur City, in India. It is located on the eastern side of the city near the river Ganges (Pavitra Ganga 2020). The area is a hub for tannery industries and has over 16000 registered industries which process leather products (Srinivasan and Reddy 2009). It has a cluster of 400 sites and discharges effluent with only primary treatment, even though it's mandatory for each tannery to have its treatment plant (Pavitra Ganga 2020). 3STPs, 339 MLD of wastewater is produced, and overall including storm water it is 767MLD (Board and Division 2010). According to the shit flow diagram (SFD) (Figure 5), it has an average of about 55% of the population of wastewater discharge, 41 % of which is transported and reaches the plant (SFD 2020). The SFD in Figure 5 details % of populations for wastewater generated and safely treated or disposed of along the service treatment chain.

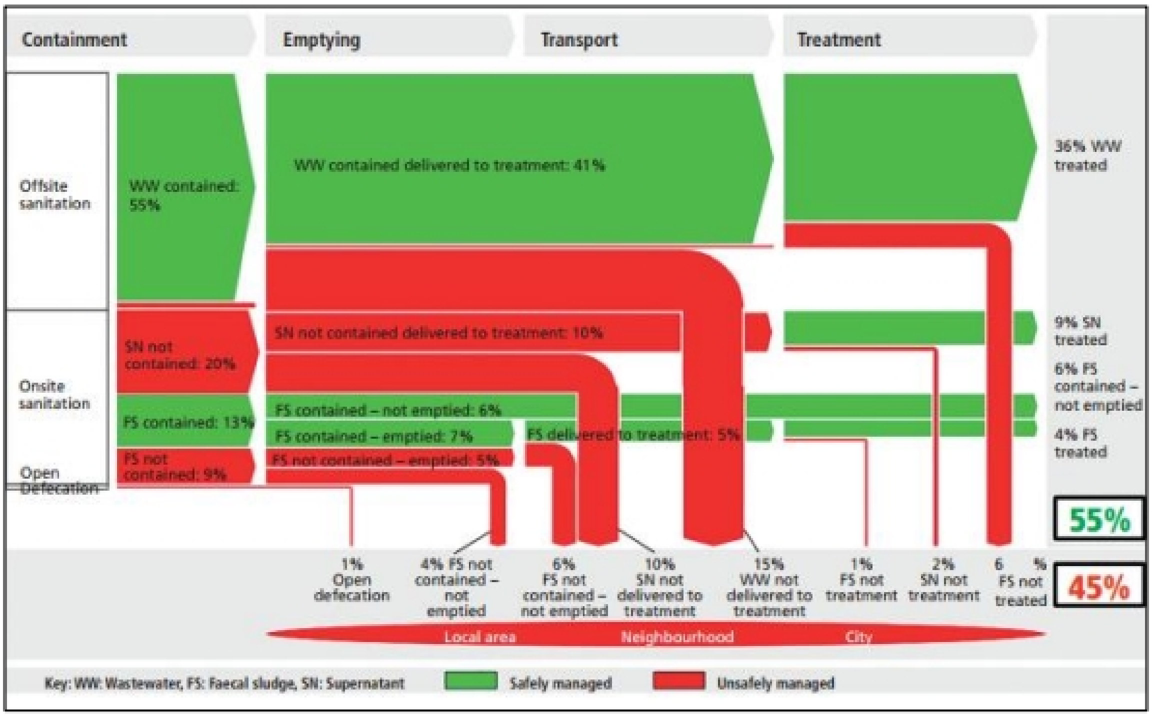


Figure 5.SFD Kanpur (SFD 2020)

3.3 Research focus area

According to baseline survey details, Kanpur has an established farming irrigation reuse scheme that benefits from the Jajmau STP/CETP(Pavitra Ganga 2020). 40 villages located downstream of the STP/CETP have irrigation benefits from the reuse scheme (Breitenmoser et al. 2022; Pavitra Ganga "n.d"). The survey further adds that 2000 hectares of land are irrigated downstream to grow rice and wheat (Pavitra Ganga "n.d"). On effluent quality, records of the Central Pollution Control Board show that Jajmau STP became operational in 1998 and 1999, It was designed to treat household wastewater effectively (CPCB 2021). However, mixtures with effluent from tanneries and other manufacturing industries were discharged through drains unlawfully (CPCB 2021). The plant has design specifications of 130MLD but treats 105MLD of mixed wastewater (Pavitra Ganga 2020). Reports further show that there's chromium in wastewater up to 16.4mg/l and active microorganisms indicate 3.3* 105FU/100 (CPHEEO 2013).

This study will focus on Alaulapur and Lalukheda. Baseline survey data show two different characteristics of villages, Alaulapur, reusing wastewater for crop irrigation, and Lalu Kheda, using groundwater for irrigation (See Table 6). The two villages seemingly all have equal resources and opportunities.

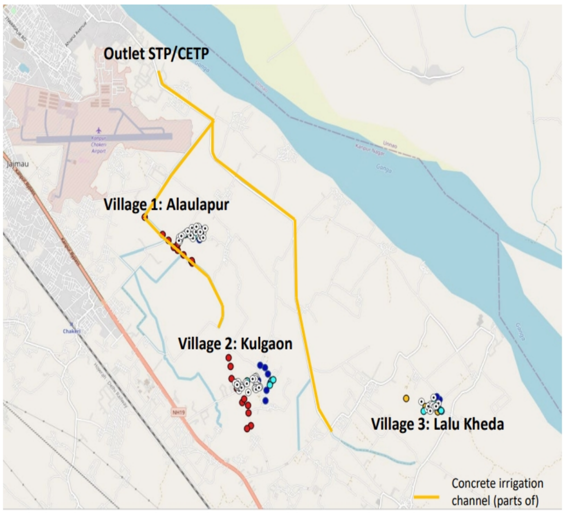
Table 6. overview of the two areas' findings from the baseline survey.

Focus	name of village	number hh	type of crops	irrigation channel	water sources	# of farming hh	# Agric land owners hh	size of average land	source of irrigation water
Case villages	Alaulapur	180	Rice & wheat	Concrete channel	10 irrigation channels,11 hand pumps,9submisable pumps.	18	13	0.125-20ha	STP/CETP
Control villages	Lalu Kheda	120	Rice &wheat	Borehole	4 Irrigation b/h, 13 hand pumps,6 submersible pumps	12	5	0.125-2.5ha	Groundwater/BH

Source: (Pavitra Ganga "n.d")

Survey baseline findings on health status indicate an increase in health conditions related to high exposure to suspected association with semi-treated mixed wastewater from the STP/CETP (Pavitra Ganga 2020; Pavitra Ganga "n.d"). The report shows heavy metal contaminants such as chromium and high-level pathogens (especially E.coli) transmission through contact or consumption, exposing the farmers by virtual occupation (Breitenmoser et al. 2022). The farmers have reportedly manifested general body malaise and frequent diarrhoea cases (Pavitra Ganga "n.d").

Figure 6 shows the main gravel channel used to discharge combined effluent (Pavitra Ganga 2020).



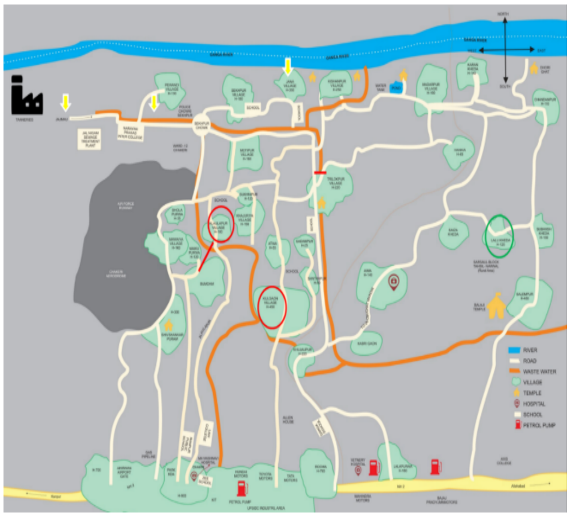


Figure 6. Reuse scheme sites Figure 7.Reuse scheme irrigation sites (Pavitra Ganga "n.d")

3.4 Research design

In this study, a life history case-control approach has been applied. The research involved a mixed approach by engaging in in-depth life histories and key informant interviews (KII). A mixed methods approach was used for data collection as it allowed for the triangulation of data explored from different perspectives, reduced errors and offset the disadvantages of other methods to achieve the research objectives (Flowerdew and Martin 2005; Flick 2017).
The study focused on two villages in a life history case-control study: Alaulapur (case village) and Lalukheda (control village). McNamara and Martin (2018) define a case-control study as an "*analytic study which compares participants who have disease or outcome of interest(cases) with participants who do not have the disease or outcome (controls*)". In this case-control study, the research compared two villages, one that uses wastewater (Case village) and the other that uses groundwater (control village). The study compared themes for the irrigation schemes, looking at the history of development, changes in irrigation practices, changes in farming practices, and changes in the health of the farmers and their families over time.

3.4.1 Data collection methods

3.4.1.1 Primary data collection

Primary and secondary data sources were applied through semi-structured interviews and life histories. This helped to provide relevant data for the study and accurately respond to the research questions. The study aimed to obtain a target of 6 KII and 20 Life history narrations to achieve the objectives (see section 1.4.2). 4 KII and 19 life histories were conducted with the farmers (see Tables 8 and 9). Table 7 below details the KII interview and the strategy.

3.4.2 Key informant interviews (KIIs)

Table 7.Overview of key informants' themes and sampling strategy. (C. Nkhoma, 2023)

Key informant	Number of interviews	Covered themes	Sampling strategy	Research question
Registered medical practitioners	2	General ailments and health issues from both sites.	Purposive	Has the health of farmers changed? Is there a difference in the health of the farmers in the different villages?
Jajmau STP Plant manager	1	The historical development of the reuse scheme	Purposive	When did they start and why (do farmers pay**, etc.**)
Jajmau STP Treatment plant workers	1	History of the reuse scheme	Purposive	When did they start**,** and why

During the research, the researcher conducted interviews with 4KII at different locations. Each interview session lasted between 30 to 60 minutes per participant. Open-ended semi-structured questions and prompts aligned with the research objectives (described in Table 7) were used. The interviews were recorded, and notes were taken on the key points. A field assistant was recruited and trained to assist with the translation from Hindi to English. No secondary data was gathered from the interviews.

(a) *(b)*

Figure 8, (a) KII interview in Alaulapur (b) life history

3.4.3 Life histories

The method allowed for in-depth sharing of experiences and captured inclusive data over time. It's an ideal method which helped to obtain silent experiences related to changes in farming practices and health over time (Bakar and Abdullah 2008). Farmers were purposively chosen from the target villages (see Table 9). The selection criteria were based on the age of participants, 55 years and over, which allowed them to provide a detailed history of the schemes from the inception year of the first STP in Jajmau in 1989. Visits were made to the case study sites, and each participant was availed a maximum of 60 minutes to share their life history story focused on the irrigation scheme and related aspects. The translator provided feedback interpretations to the researcher throughout the session from hindi to english. the researcher took notes of the critical points and the sessions were recorded with the permission of the respondents. Additionally, a time chart was made to help with activity triggers and focus on the theme during the session.

(a) *(b)* *(c)*

Figure 9 above shows life history (a) Alaulapur, (b) Lalukheda and (c) Alaulapur.

3.4.3.1 Secondary data

The Pavitra Ganga data from the project website and Pavitra Ganga data from the project research papers focusing on types of crops being grown, health effects and the form of irrigation methods used. Agricultural policy literature from other similar projects, wastewater irrigation from online sources, and general articles and journeys from across the globe.

3.4.3.2 Data analysis

This study used thematic analysis to interpret and analyse data from note-taking and recordings, including translated responses. The organised data was analysed and summarised to identify themes related to the objectives (see Section 1.4). Life history timelines comprised activity comparisons in the theme of historical trends between the case and control villages. Appendix C includes the developed KII guide, row data narratives for KII, and life history.

Table 8 Codes adopted for key informants (C. Nkhoma, 2023)

key informant	context	location	language	number of participants	codes
STP manager	History of scheme	Alaulapur	English	1	K-01
Former STP worker	History of scheme	Alaulapur	Hindi	2	K-02
Community Medical Practitioner	The health of farmers and villagers	Alaulapur	Hindi	1	K-03
Pharmacist	The health of farmers and villagers	Lalukheda	Hindi	1	K-04

Table 9 Codes adopted for life history (C. Nkhoma, 2023)

life history	context	location	language	number of participants m	f	codes
Farmer	Life history of the scheme, farmers' practices and health	Alaulapur	Hindi	08	01	A-01- A-09
Farmer	Life history of the scheme, farmers' practices and health	Lalukheda	Hindi	10	0	L-01- L-10

Chapter 4 **Results and Discussion**

This chapter will discuss the findings and generate a comprehensive discussion based on the key informant interviews (KII), the life histories of farmers, and secondary data from relevant papers and reports from the Pavitra Ganga project. The aim is to achieve the study's objective (see section 1.4).

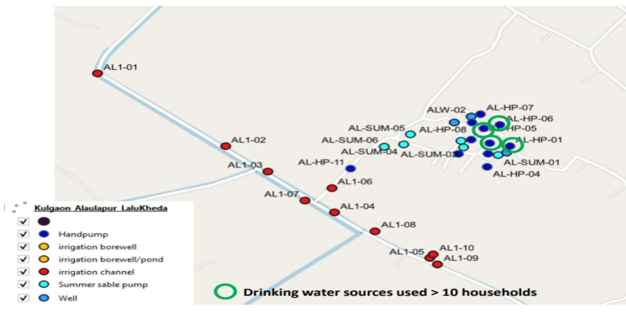
4.1 History of the wastewater reuse scheme in Kanpur

4.1.1 Construction of irrigation channels in Kanpur

According to K-01 in 1950, the government constructed gravel channels to aid with the irrigation of crops using drainage discharged raw sewage and river water mixture (see Figure 10 (a- b)). Before 1985, the Indian government maintained main gravel channels in 26 villages (A-07). In the summer of 1995, stones were added to the village drainage channels, together with sand (A-07). These channels were supplied with combined irrigation wastewater from the Ganga river and STP, which contained essential minerals for crops before the inception of the CETP (Singh 2006). The Kanpur metropolitan council (KMC) upgraded the main channels to more durable concrete for irrigation extending to the villages in 2013 (see Figure 11) (K-01).

K-02 observes that 1994 indicates a significant shift from the channel receiving Ganga river water to a mixture of STP water and CETP, causing harm to agricultural produce. As a measure of response, A01 says, "*We were permitted to use tannery mix water for irrigation as a measure to conserve fresh water from the Ganga river*". According to the baseline survey, it shows that 10 channels were upgraded for use in Alaulapur village (see Figure 6 and 10(b)) (Pavitra Ganga "n.d"). (K-01) observes that "*farmers rely on channels for irrigation with no alternative water sources*" (as described in section 3.3). K-01 goes on further to add, *"the irrigation water is transported through a 4km concrete route to irrigate approximately 2000 hectors of peri-urban agricultural land"* (see Figure 9(a)) (K-01). This information aligns with the details of the baseline survey, which says about 40 villages downstream of the Jajmau STP are beneficiaries of the wastewater irrigation scheme (see section 3.3) (Pavitra Ganga "n.d"). (Figure 10 (b)) map showing the existing 10 main channels that were upgraded to concreted and sub-gravel channels into personal farms (Pavitra Ganga "n.d").

(a)



(b)

Figure 10 (a) & (b) concrete main channels (C. Nkhoma, 2023) (Pavitra Ganga "n.d")

4.1.2 **Jajmau sewerage treatment plant and history**

The Utter Pradesh Jai Nigam (water supply and sewerage) launched 6 STPs in the Kanpur metropolitan area under the Ganga Action Plan (GAP) phase 1 in 1985 (see section 2.3.3, Figure 4) (Shende and Pophali 2022). Out of these, 3 STPs were installed and operated in Jajmau (Singh 2006). A pilot sewerage treatment plant based on the "up-flow Anaerobic Sludge Blanket" technology was built in 1989 to treat 5 million litres of domestic wastewater daily (MLD) (see Figure 11) (Kanpur Nagar Nigam 2006). The plant received illegal discharges of tannery effluent and had to discontinue receiving tannery effluent due to its negative impact on the UASB process and the quality of effluent discharged for agriculture use (Kanpur Nagar Nigam 2006; Singh 2006). Consequently, a wastewater treatment plant for processing wastewater and tannery effluent from the 175 tanneries, named a common effluent treatment plant (CEPT), was built in 1994 after assessing the pilot plant performance (as described in section 3.3) (Kanpur Nagar Nigam 2006). It was designed to treat 36 MLD combined tannery effluent and domestic wastewater as the main STP linked to the irrigation scheme (Kanpur Nagar Nigam 2006; Singh 2006). In January 1999, a sewage treatment plant (STP) utilising the "Activated Sludge Process" (ASP) with a capacity of 130 MLD was constructed and brought into operation (as described in section 3.3). The primary purpose was to treat domestic wastewater. However, after its commissioning, unauthorised discharges from tanneries and multiple industries within the cities nearer areas have emerged and all discharge effluent (Kanpur Nagar Nigam 2006; CPCB 2021).

The tannery industry had gained prominence in Kanpur as highlighted by K-01, stating that *"the tannery industry has been present in the area since 1954, but there were few industries then, in 1986 there were around 175 industries and currently more than 400 exist illegally registered and discharging effluent"* (see section 3.2). As reported by Pavitra Ganga (2020), the rise in tannery effluent from 9 MLD to 26 MLD posed a challenge to the functioning of the treatment plant, as mentioned in the previous paragraph. This surge in tannery effluent, along with other industrial wastewater, including leather flushing and chromium sulfides, was being directed to the common effluent treatment plant (CEPT), causing corrosion and reduced efficiency (Singh 2006). The inadequately designed CETP has seen environmental and operational issues in discharging standard effluent (Kanpur Nagar Nigam 2006).

According to K-01, *"the effluent from the STP had a biochemical Oxygen demand (BOD) range of 20-30-MG"*, indicating a slightly higher range compared to the Indian standards (see section 2.3.3, table 5). In contrast, the CETP had higher BOD levels, ranging from 70 to 100mg, surpassing acceptable limits. Total dissolved solids (TDS) were also a concern, with the CETPs effluent containing concentrations of over 10,000 mg, above the permissible limit of 2100 mg/L (CPHEEO 2013; Babalola et al. 2023). K-01 adds that during monsoon season, increased rainfall leads to high water levels in the channels, resulting in a greater discharge volume into the village. The composition and concentration of effluent chemicals discharged into the channels vary by month, with the most toxic months being November to January (A-09).

Figure 11 displays a timeline for the Jajmau wastewater reuse scheme in Kanpur, illustrating the evolution of events before the scheme began. Data was collected through life histories and key informants.

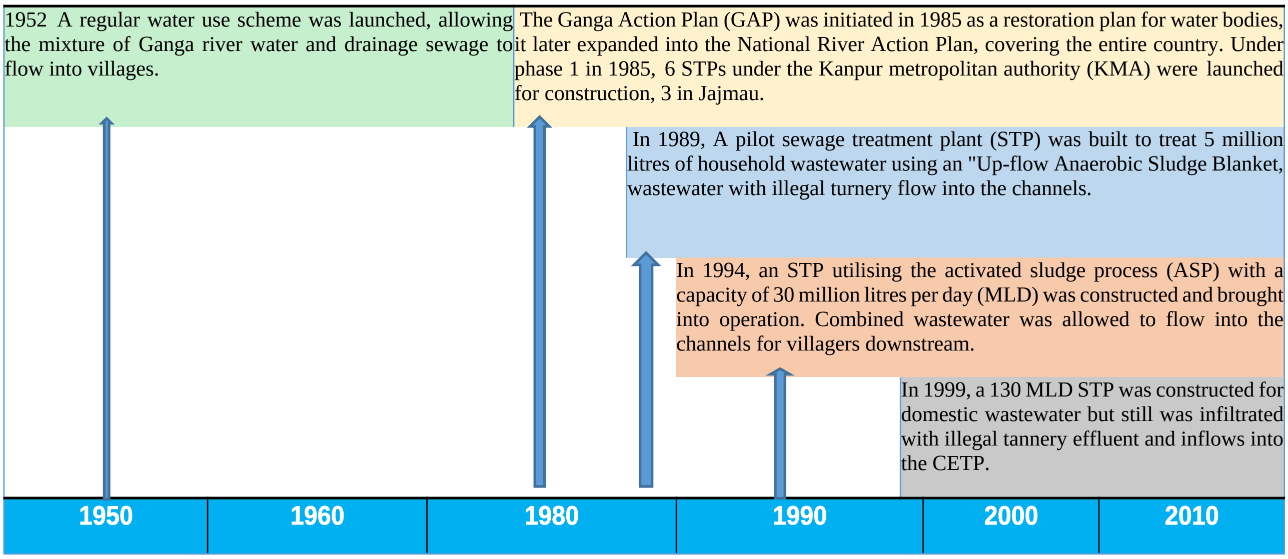


Figure 11 summary of the wastewater reuse scheme in Kanpur (C. Nkhoma, 2023).

4.2 Changes in irrigation practices in Alaulapur and Lalukheda

The timeline below illustrates the evolution of irrigation practices in Alaulapur and Lalukheda villages in Kanpur, India—data captured from life histories.

	1950s	1960s	1980s	1990s	2000s	2010s
Alaulapur					Over 100 tanneries were built in Jajmau, discharging effluent for irrigation into the villages.	Currently, more than 378 tanneries exist and discharge effluent for irrigation into the villages.
Alaulapur	Farmers relied solely on rainwater for irrigation.	The Kanpur development board introduced sewage effluent and Ganga river water mix for irrigation into the villages.	1989, Farmers were meant to use wastewater from the STP combined with illegally discharged tannery effluent for irrigation.	Tannery effluent was allowed to mix with wastewater from the sewage treatment plant (STP) after the construction of the common effluent treatment plant (CET charged into the channels for villagers to use in irrigation farms. 2000 hectors of land is irrigate in village farm land.		
Alaulapur		Gravel channels were constructed through government support, and famers were meant to pay tax for water use.		In 1995 summer, stones were put in gravel channels with sand		Gravel drainage channel improved to concrete
Alaulapur					2000, Irrigation water was tested after introducing combined wastewater and tannery effluent in the village. Water survey conducted for boreholes less than 80ft deep.	
Lalukheda	Irrigation farming was done using rainwater and shallow well water.			Began to use borehole water with submersible pumps	Farmers started using poly pipes to connect submersible pumps for the irrigation of crops	Electricity was introduced in the village and a boost to the running of irrigation pumps
Lalukheda		Farmers began using diesel engines to irrigate newly expanded land with water from shallow wells.		Farmers started drilling boreholes and connecting the diesel engines for irrigation through the gravel furrows		2013 payment for electricity use

Figure 12 timeline summary of changes in irrigation practice (C. Nkhoma, 2023).

4.2.1 Changes in irrigation practices in Alaulapur.

Before 1950, the villages solely depended on rainwater for farming (see Figure 12) (A-02, A-04, A-07, A-08). In 1952, the Kanpur development board introduced a significant change by establishing a system that brought sewage and river water for irrigation, reducing the reliance on rainwater (a-02, a-04, a-06, a-08).

By the 1980s, the situation shifted due to declining Ganga river water levels and contamination concerns (See Figure 12) (A-01 to A-09). This development agrees with the period of the Green Revolution after 1960 when the government of India introduced new varieties of crops which needed adequate irrigation water and machinery to sustain growth (see section 2.3.2) (Gulati and Juneja 2020a). The village was compelled to adopt a new approach of using mixed wastewater from the STP and the CETP to irrigate crops (section 4.1.3). This shift was driven by the necessity to find alternative water sources, protect the Ganga and ensure the production of adequate food (A-01, A-04, A-06, A-08, k01) (Gulati and Juneja 2020a).

According to K-01, farmers are subjected to pay for wastewater use under the scheme, but the amount is little "*farmers pay to the Kanpur metropolitan authority for use of irrigation water, but I don't know how much it is exactly, it's a little quantity and not all of them pay because it is a leasing land area*". However, Amerasinghe et al. (2013) reaffirm that compliance with this requirement to pay is inconsistent, often due to its association with land leasing. A-06 notes that farmers were exempted from taxes for irrigation water but obliged to pay taxes for the land designated to them by the local authority, further emphasising that paying became their sole source for cultivation to grow crops.

According to (Amerasinghe et al. 2013), wastewater irrigation was supported by municipalities whereby treated effluent was discharged into specific locations for a fee so that the farmers could cultivate crops and ensure the maintenance of the channels.

Several drivers were involved in adopting wastewater and tannery effluent for irrigation (A-01 to A09). The early inception was influenced by the cultural factors related to the caste system. According to A-01, he says, "*My village doesn't have fresh water because of our caste system, this is the only water provided for us to grow crops, in 1980s the government blocked this village from accessing fresh water from the Ganga river by saying the water level has become low".* The shift in 1989 was driven by the worsening of the Ganga river and was influenced by the creation of the Kanpur development board (see section 4.2 Figure 12) (A-07).

Gravel channels were installed to support irrigation throughout the villages and later upgraded to concrete channels to enhance irrigation (see Figure 10 (a)) (a-07). Farmers would individually spread the furrows into their farms (see Figure 13(b)) (A-03).

(a) (b)

Figure 13 (a) gravel channels into farmlands and (b) flooded fields with combined effluent. (C. Nkhoma, 2023)

4.2.2 Changes in irrigation practices in Lalukheda

As early as 1976, farmers started switching from traditional irrigation methods of flooding their fields, such as shallow wells and gravel furrows, to more mechanised techniques of drilling boreholes supported with PVC pipes, sprinklers and drip irrigation (see Figure 12) (L-01 to L-10). A significant shift to electric pumps occurred in 2013, highlighting collective recognition of enhanced efficiency and sustainability (L-01 to L-10). The choice for the transition was driven by effectiveness, expansion of irrigation area and electricity availability, while diesel fuel expenses primarily influenced part of the decisions (L-01 and L07).

Furthermore, according to the farmers, they have invested substantially in submersible pumps to enhance their irrigation methods "*The government has not been involved, everything has been personal. The government has provided subsidy services like tractors and a few model pumps for those with money to buy over time" (L-03) (see Figure 12).* According to government policy for the implementation of the Green Revolution, supported the mass availability of affordable fuels for mechanised equipment, including submersible pumps for irrigation towards a variety of crops introduced on the market (see section 2.3.2) (Gulati and Juneja 2020a; Gautam et al. 2023). A compelling aspect is the collaborative nature of irrigation development. L-06 and L-07 emphasise sharing water resources with the community and neighbouring families. The shift is driven by efficiency and improved affordable technology. (see Figure 14 (a-b)), reflecting on the development of irrigation options to support farming in the village.

(a) (b)

Figure 14 Lalukheda PVC pipes supporting irrigation with an electric switch room (C. Nkhoma, 2023)

4.2.3 The differences between irrigation practices in the Villages

From around 1950 to 1980, the farmers in Alaulapur and Lalukheda used rainwater for irrigation. The two villages have similar historical foundations rooted in family settlements where farming constitutes the primary occupation of their lives (see Figure 12) (A-01 to A09: L-01 to L-10). Alaulapur outlines a shift from rainwater-dependent agriculture of growing seasonal crops to the introduction of sewage and river water mixture for irrigation in the 1950s, and later transitioning into combined wastewater (A-01 to A09). The availability of wastewater has led farmers to rely solely on combined wastewater for crop irrigation (Kanpur Nagar Nigam 2006). According to Angelakis and Bontoux (2001), the use of wastewater in irrigation significantly reduces the pressure on freshwater sources, adding that it's an option, especially climate change developments (see section 2.2.1). Lalukheda highlights a shift from traditional irrigation, such as wells and gravel furrows, to modern mechanised techniques, such as diesel-electric submersible pumps and private boreholes (as in Figure 14 (a-b)) (L-01 to L-10). Meanwhile, Gulati and Juneja (2020b) say irrigation was highly enhanced during the Green Revolution through incentives in irrigation equipment to support growing of rice and wheat varieties (see section 2.3.2).

The villages have diverse approaches to irrigating crops, Alaulapur relied on flooding of wastewater for rice and wheat, while Lalukheda used shallow wells and gravel furrows and later shifted to modern mechanised techniques of drilled boreholes supported with PVC pipes (see Figure 14 Lalukheda (a) and Alaulapur (b)).

Notably, in 2013 for Alaulapur, concrete channels were introduced, enhancing wastewater delivery efficiency (A-06, A-07, A-08, A-09). Alaulapur stresses the significance of the governments participation in constructing irrigation channels made of gravel and concrete. In contrast, Lalukheda suggests taking self-reliant measures and using borehole water sources (see Figure 12). Farmers from both villages display resource maximisation strategies, an illustration of adaptation to existing resource constraints. Alaulapur community collaboration is on channels for irrigation, focusing more on the shift in water sources and their impact on agricultural health (A-02 to A-09). Lalukheda highlights collaborative aspects, including sharing water resources with the community and neighbouring families.10 households share a bore each to connect irrigation pipes an our each per day (L04).

4.3 **Historical changes in farming practices for Alaulapur and Lalukheda**

This timeline chart shows evolution of changes in farming practices in Alaulapur and Lalukheda villages that use wastewater and groundwater for irrigation schemes respectively. Information collected from Famers Life Histories.

Timeline

Village	1950s	1960s	1980s	1990s	2000s	2010s
Alaulapur	Famers used pesticides for crops		1989, farmers stopped using pesticides as the crops grown didn’t require them			
Alaulapur	Farmers fertilised their soil with cow dung.	Most farmers didn’t use any organic supplement for soil as the wastewater and Ganga river mix was assumed to have nutrients.	1989, Started using conventional fertiliser as the infiltration of tannery effluent increased.	1994, Most farmers stopped using conversational fertiliser and cow dung, due to flooding and high chemical concentrations from the discharged effluent.		
Alaulapur	Farmers used cattle and water buffalos for land preparation/ cultivation practices as traditional practice of many years.				2003 Farmers started using Tractors for land preparation and cultivation of land which was more efficient and cheaper cost	
Alaulapur	Farmers grew all crops without challenges, such as corn, chilli, and cauliflower. bananas, tomatoes, vegetables, flowers, okra			Limited crops are grown, only wheat, millet and rice.		
Lalukheda	Growing all crops on the market, mangos, flowers, corn, sugar cane, okra, cucumber, watermelon, rice, wheat, millet, pumpkin, tomatoes, onion, chilli, garlic, Farmers practise rotational crop cultivation, growing all crops based on the season.					
Lalukheda	Farmers relied on cattle and water buffaloes to cultivate their land.				The gradual shift from animal-based cultivation	2003 complete shift to use of tractors for land preparation/ cultivation
Lalukheda	Farmers used cow dung for soil nourishment			Farmers use cow dung and fertiliser at different proportions depending on the need and availability of cow dung.2010 fertiliser subsidy policy supported the uptake		
Lalukheda			Some farmers introduced pesticides to support crop growth			

Figure 15 historical changes in farming practices (C. Nkhoma, 2023)

4.3.1 **Changes in farming practices in Alaulapur**

Farmers used pesticides to grow all crops before the introduction of tannery water in the late 1980s (see Figure 15). Farmers stopped using pesticides as the crops which were grown didn’t require sustainability of growth using pesticides. A-01 says *“It’s just an extra cost as no pest can survive in the wastewater which is too concentrated, not even snakes can be found”*.

Traditional farming practices involved the use of animals before 2003 (see Figure 16 (b)). It involved buffalos and cattle with oxcarts for ploughing fields as a practice picked from generations and carried on (A-01 to A-09). In 2013, tractors replaced animals due to efficiency and time saving benefit (see Figure 16 (b)). It started became challenging to adequately feed animals to cultivate expansion land for growing more crops (A-01 to A-09).

Farmers started using conventional fertilizers in the early 1980s (as described in section 4.3.1 Figure 15). As the infiltration of tannery effluent increased, most farmers stopped using conventional fertilisers and cow dung due to flooding and high chemical concentrations from the discharged effluent (A-09). Before 1980, a variety of crops thrived (see Figure 15). The introduction of tannery effluent changed the agricultural landscape, making only rice, millet and wheat viable due to their tolerance to chemicals (A-01 to A-09). (see Figure 16 (a)), showing the different methods of growing crops, and flooding of wastewater for rice and wheat.

(a) (b) (c)

Figure 16 different methods of agricultural practice (C. Nkhoma, 2023)

4.3.2 Changes in farming practices in Lalukheda

From the early 1950s, Farmers in the village practiced rotational crop cultivation, growing all crops based on the seasonal (see Figure 15) (L-01 to L-10). The variety of cultivated crops suggests a diverse approach to farming, likely influenced by the changes in market demand and economic considerations (figure 17 (b)) shows okra being grown as a variety crop. Crop rotation and the cultivation of various crops highlight farmers' adaptability to different seasons and changing needs in the market (L-01 to L-10). The introduction of flowers as a crop in some sections reflects the farmers' willingness to explore new profit opportunities (L-07 to L-09).

Farmers relied on cattle and water buffalos to cultivate their land. It became apparent that feeding the animals was becoming excessively expensive, and the amount of land requiring cultivation had grown (L-01 to l-10). Since 2003, a clear shift has been made towards adopting modern technologies such as tractors for more efficient and cost-effective farming (L-01 to L-10). Farmers use cow dung for soil nourishment at different proportions depending on the need and availability (L-07 to L-09). Before 1990, cow dung was most farmers' primary source of soil fertilization. However, as cultivation land expanded, the availability of cow dung decreased significantly (L01 to L-10). As a solution, the village has intensified the use of fertilizer which correlates with the national wide use of fertilizer taking advantage of the existing subsidy policy for famers, “the central government launched the nutrient-based subsidy policy in 2010 for P and K fertilizer, the policy was formulated to promote a balanced use and access of N, P and K fertilizers” (Sharma and Thaker 2010; Deshpande 2017). A minority of farmers persist in suing cow dung (see Figure 17 (c)). Some farmers introduced pesticides to support crop growth for most crops grown that require pests and have been using them since the early 1970s (L-08).

(a) (b) (c)

Figure 17 pipes laid to supply water and cow dung for application. (C. Nkhoma, 2023).

4.3.3 The differences in the farming practices between Alaulapur and Lalukheda

Before the introduction of combined effluent, pesticides were commonly used for a variety of crops (as in Figure 15), after its introduction, farmers considered pesticides as an extra cost (A-08). They believed that wastewater was too concentrated for pests to survive and that it acted as a deterrent to pests, *" the chemical composition is generally too high, and hence no insects or snakes in the water could survive, it's the reason we also don't use pesticides because we feel its wastage as the chemicals are usually too strong*" (A-09). Whilst in Lalukheda, crops still required pest control, some farmers continued to use pesticides and have not stopped from inception (L-01 to L-10).

Before 2003, farmers in both villages relied on buffalos and cattle for ploughing fields (A-01 to A09:L-01 to L-10). This practice had been passed through generations and was a traditional method of farming, indicating a slow and labour intensive process, feeding the animals was a significant expense. As the amount of land requiring cultivation grew, this expense became a burden due to the need to provide sufficient food for the animals (A-01 to A09:L-01 to L-10). After 2003, Tractors replaced oxcarts as the primary means of ploughing fields in both villages. This shift was driven by the desire for efficiency and time saving benefits. Tractor rentals became available and cheaper as stated by (A07) "*Large acres of land is cultivated and have proved to be cheaper because I don't provide food to animals, and it cost less to hire a tractor for an hour".* According to Gathorne-Hardy (2016), the practice of using tractors is an emerging development in agricultural practice in India and compares with the current happening where both tractors and animals produce relatively equal emissions of greenhouse gases(GHG), but the efficiency has been the reason for the shift. Further, Gulati and Juneja (2020a) state that, one of the objectives of the Green Revolution in India was to ensure the mechanisation of agriculture by making equipment and machinery affordable through local manufacturing of different models in huge numbers, he adds that the Indian government de-licenced manufacturing of tractors to support agriculture growth (see section 2.3.2).

In Alualapur, fertilisers were used during around 1950 to 1980 before the combined effluent was introduced (as described in Figure 15) (A-01 to A-08). Farmers started moving away from traditional fertilisers and cow dung because tannery effluent was seeping into the soil, they believed that the effluent provided enough nutrients for the soil, but it also washed away the fertilisers and cow dung (A-01 to A10). They are worried about toxic metals and other harmful substances that have made their way into the food chain through the soil. Local communities have claimed this is due to inadequate effluent treatment resulting from STPs and CETPs (Singh 2006; Kesari et al. 2021b). This has reduced yields and the inability to grow marketable crops like flowers, leading to decreased daily income. In contrast, the lalukheda shift was due to the decreasing availability of cow dung in the community, due to the expansion in crop diversification, leading to the introduction of fertilisers (see Figure 15). However, some farmers continue to use cow dung alongside fertilisers, indicating a mix of traditional and modern practices in response to changing circumstances (see section 4.3.2).

Before 1980, farmers in Alaulapur grew a diverse range of crops (as indicated in section 4.2, Table 15). The introduction of combined effluent in 1990, changed the agricultural landscape in the village, a few crops remained viable. This suggests a significant reduction in crop diversity as a result of the introduction of these effluents. Farmers are constrained in their crop choices due to the chemical composition of the wastewater. Whilst in Lalukheda from the 1950s, famers practised rotational crop cultivation, growing a variety of crops based on the season. Accordingly, a wide range of cultivated crops highlights diversity in farming practices (see section 4.2, Figure 15). Some farmers (L-07) introduced flowers as a crop, reflecting the farmer's willingness to explore new profit opportunities and indicating adaptability to changing market demands and desire to explore alternative sources of income.

4.4 Historical changes in the health of farmers and their families in Alaulapur and Lalukheda

The Figure below shows the changes in health trends over time in two villages located in Kanpur, India. Alaulapur village uses combined wastewater, and Lalukheda uses groundwater for irrigation schemes. The information was gathered through life history interviews conducted with local farmers.

Timeline evolution of health changes

	1950s	1960s	1980s	1990s	2000s	2010s
ALAULAPUR	Only common illnesses, fevers, diarrhoea, cough and malaria, dengue virus		The introduction of tannery effluent for irrigation led to skin infections among farm workers, which was previously uncommon	• Increased Skin diseases, roundworms, blister patches, rashes, dental problems and diarrhoea, dengue virus became prevalent due to high chemical concentrations in irrigation water. • Cases of lung infections, cancers, gum cancers, and liver problems were reported. Increased dental decay, tobacco intake and alcoholism • An increased number of eye infections and hair turning grey for farm workers. • Men not seeking health services. • Babies got affected by skin conditions through their mothers.		
ALAULAPUR				Health is averagely poor, with less food available.		
LALUKHEDA	Mild development of ailments like coughs, flu, and other unknown sources of illnesses was observed.				Dental and tooth problems and mild respiratory infections were observed, potentially linked to tobacco consumption and pesticides.	The health of farmers improved after less work in the field to cultivate manually.
LALUKHEDA					Many individuals reported relatively stable health conditions, with mild fevers and occasional illnesses like coughs and flu.	Introducing electricity meant more crops produced and enough food for consumption.

Figure 18 evolution of health events in Alaulapur and Lalukheda villages (C. Nkhoma, 2023)

4.4.1 Changes in the health of famers and their children in Alaulapur

Between 1950-1960, common illnesses were fevers, diarrhea, and malaria (A-02, A-03, A-04, A-07, & A-09). Before the introduction of tannery effluent, health problems were few with no severe complications or skin infections (see Figure 18). Faecal oral diseases were less common (A-07). According to K-03, after 1985, villagers presented more illnesses such as diarrhoea, skin rashes, stomach problems, and liver problems. This came with the introduction of tannery effluent for use in irrigation these infections became widespread among the farm workers, with symptoms ranging from rashes and blisters patches to more severe cases that persisted over time (A-04, A-05, A-06, A-08). Some community members developed unusual health conditions as described by (A-08), "*my father developed gum ulcers which developed into cancer, and from 1995, 45 persons in the village were infected with skin and gum cancers*". This is believed to be linked to exposure to contaminated water (A-08). The high concentration of chemicals in the water causes health complications, affecting physical health and workability (Amerasinghe et al. 2013). Alaulapurs community complaints are more pronounced with visible ulceration, callous tissue formation, heavy skin irritations and dark fingernails (A-08, A-09).

K-03 described increased dental decay, tobacco intake and alcoholism as emerging problems. K-01 further explains that "*on overage, I attend to about 20 patients with skin infections and diarrhoea daily, but I can't confirm if the skin infections are cancer caused by the irrigation water we use, though too much tobacco which men have swallowed leading to suspected gum cancer and a lot of lung infections*", (see Figure 19 (a)) showing a patient captured at the medical practitioners place seeking rash infection treatment. Overtime, the health effects of exposure to tannery effluent which contains high levels of heavy metal contaminants such as chromium and high-level pathogens (especially E. coli), have begun to manifest (as described in section 3.3) (A-08, A-09). According to Singh et al. (2004), a research on the effects of exposure, farmers have significantly higher scores for neurobehavioral function tested, than the controls, and urine and blood samples of residents working in the wastewater sites of Kanpur had heavy metals and pesticide residues suggesting long term impacts can be expected unless exposure is minimised. A-08 refers to the cancers reflected as being caused by tannery effluent exposure. "*The manifestation of these cancers began between 2015 and 2021, and some individuals reportedly died due to the long-term effects of working on the farms with the contaminated effluent"* (A-08, A09). The long-term effects of exposure to contaminated effluent are leading to an increased number of eye infections and premature greying of hair among farm workers (A-08, A-09). Unfortunately, men are not seeking health services and babies get infected by skin conditions through their mothers, this compares to (Van der Hoek et al. 2002) research that quite often use of wastewater takes a gender role. The overall health of the community is quite poor, with limited availability of a variety of foods (A01 to A-09).

4.4.2 Changes in the health of farmers and their children in Lalukheda

According to L-0, in the period between 1950 to 1990, mild developments of ailments like coughs, and flue were observed. K-04 says most people only get to visit for coughs and fever in babes, "most *farmers and their families have never had severe health problems apart from Covid-19 in 2020"* he observes that "farmers *with other ailments prefer to buy drugs in town and directly seeking of services in town than with me*". Farmers and individuals leading normal lives have experienced minor health changes, including usual fevers, without significant concern(L-02) (see Figure 18).

Major health changes have not been observed due to consistent lifestyles, except during monsoon seasons when stagnant water leads to malaria outbreaks. In 2000 tooth problems emerged with mild respiratory infections, potentially linked to tobacco consumption and pesticides by the farmers (K-03). *"I have only attended to farmers who develop rash maybe after spraying in the fields with pesticides then proceed to buy tropical applications*". Since 2010, economic growth has led to better health for farmers selling a variety of crops and fewer unusual illnesses (L-01 to L-10). Dengue fever cases have decreased. Family health has remained stable since 1978 despite introducing pesticides on crops (L-09). Lifestyle changes include travelling to town for medical check-ups.

4.4.3 The differences in the health of farmers and their children between the villages

Farmers in Alaulapur had common illnesses like fevers, diarrhoea, and malaria in the 1950-1960 period, while Lalukheda observed mild ailments like coughs and flue during the 1950-1990 period (see Figure 18). The Farmers highlighted severe health effects due to exposure to tannery effluent (see section 4.4.1), including cancer, skin infections, lung infections and dental decay, and that their health is generally poor (see section 2.1.2).

Farmers, their children, and the consumers of their crops face a variety of hazards from exposure to physical, chemical, and biological contaminants (Babalola et al. 2023). Jiménez (2006), agrees that the use of wastewater for irrigation can result in diseases such as cholera, typhoid, giardiasis, amoeba and shigellosis, which can easily spread through vulnerable populations. There are also gender implications of using wastewater for irrigation, as crop cultivation often requires labour input that is primarily provided by females, thereby increasing the risk of pathogen transfer to other family members, especially during evening cooking chores upon returning to households (Van der Hoek et al. 2002).

In contrast, Lalukheda didn't experience such severe health consequences. Farmers in Alaulapur experienced health changes over a broader period (1950- 1960 and post -1985), while Lalukheda farmers focused on two specific periods (1950-1990 and post-2010s), with mild health developments. (K-03) mentions that Lalukheda experienced economic growth contributing to improved health in the post-2010s period arising from the diversity in the crops grown and adequate food, which was not the case in Alaulapur as crops grown are restricted to starch (refer to Figure 15). Alaulapur showed a decline in health after the introduction of combined effluent, with severe health problems emerging, whereas Lalukheda indicated an overall improvement in health in the post-2010 period.

(a) (b)

Figure 19 (a-b) patient showing skin infection and KII. (C. Nkhoma, 2023*)*

4.5 Relationship between villagers' health and the reuse of wastewater

The wastewater reuse scheme in the villages along Jajmau STP has been in place since 1989. The government supports this scheme by maintaining channels that allow farmers to access the combined irrigation wastewater in the village (see section 4.1.2). According to baseline survey data (Pavitra Ganga "n.d"), the two areas under the case study have similar conditions and only differ on the type of water used for irrigation as a main difference (see section 3.3, table 6, figure 12). The introduction of the wastewater reuse irrigation scheme drove changes in not only irrigation practices between channels and boreholes but also farming practices in the cultivation and growing of different crops. The farmers in the villages believe that the wastewater from irrigation schemes has caused health issues (as shown in Figure 18).

Although the villages are similar in terms of resources, farmers in Alaulapur have experienced health changes over a longer period (1950-1960 and post -1985) (refer to Table 13). This suggests a longer and sustained impact of exposure to wastewater and later combined effluent use. Between 1995 and 2004, there were major problems with skin, lung, and cancerous conditions, indicating a potential correlation with exposure to chemical contamination of heavy metals such as chromium over time (refer to section 2.1.2, figure 3). One farmer in his narration share that "*from 1995 to 2004, four farmers died and two others are still alive; we believed these illnesses were caused by water because the concentration of chemicals is usually too high*" (A-04). This correlates with the findings according to Babalola et al. (2023), farmers, children and individuals who consume harmful crops can face various risks associated with exposures to physical (as malodour and skin irritants), chemical (heavy metals) and biological hazards(such as microbial pathogens, soil-helminths and vector – related diseases). The individuals at the highest risk of feacal oral diseases have direct exposure to irrigation wastewater during farming activities or medium risk of exposure to these hazards (Kesari et al. 2021b; Hossini et al. 2022; Babalola et al. 2023). In contrast, Lalukheda faced mild health developments (see Figure 18).

The health of the two villages differs from each other, (as shown in Figure 8). Although they have similar resources according to the bassline study (Pavitra Ganga "n.d"), the introduction of combined wastewater in Alaulapur resulted in reduced crop diversity, which is discussed in section 4.3 and Table 12). This shift in agriculture has potentially affected the nutritional diversity of villagers' diets and impacted the health of farmers and their families. The decline in health has been associated with limited crop options, mainly restricted to starch crops. Alaulapur is facing poor crop yield development due to chemical infiltration. This compares to the research study in Vietnam which estimated a reduction in the yield of waste irrigated rice by 10-13% due to water pollution, the effluent causes a reduction in height, leaf area and dry matter (Khai and Yabe 2012). Song (2004) estimated a reduction in yield rate of 20%. The quality of wastewater used in crop growing makes famers and villagers more susceptible to diseases. However, Lalukheda's economic growth has led to improved health since the 2010s. This improvement can be attributed to crop diversity and sufficient food supply. These economic factors have played a significant role in enhancing the health outcomes of the villagers (see Figure 18).

To adapt to changing environmental conditions, Alaulapur village uses combined wastewater and tannery effluent for the irrigation of crops. This has caused problems with direct and other forms of contact, resulting in health and microbiological issues related to exposures to Escherichia coli (E. coli) and chromium contaminants in wastewater (as discussed in section 2.1.2, figure 3). On the other hand, Lalukheda village adopted more modern irrigation practices that focused on cost efficiency and technological advancement (see section 4.2.2). While this may not have direct health-related implications, it could indirectly affect villager's health by influencing their economic well-being. Over time, farming practices shifted from using traditional animal-driven ploughs to tractors, driven by the need for efficiency and cost savings (see section 4.3.1). Tractors are faster and more powerful, reducing labour requirements and physical strain on farmers. This transition has positive implications for farmers' physical well-being and health by lessening the physical demands of farming.

Raising awareness about wastewater usage practices is crucial for farmers to proactively respond to health awareness (Babalola et al. 2023). In the early 2000s, residents from Alaulapur expressed concern and staged protests against the use of contaminated irrigation water. Water analysis revealed high levels of Escherichia coli (E. coli) and chromium, which worsened the scarcity of safe drinking water (refer to Figure 20(b)). Despite the protests, the government continued to discharge effluent from tanneries, leading to further chemical contamination. To reduce chemical contamination in portable drinking water, deep hand pumps were installed (see Figure 20(a)). A study by Breitenmoser et al. (2022), found that the presence of chemicals and biological health risks, such as high concentrations of chromium and feacal coliforms makes irrigation water unsuitable for human beings' occupation activities.

(a)

(b)

Figure 20 pottable water sources(a) Lalukheda (b) Alaulapur

Chapter 5 **Conclusion**

In this study, we conducted life history narrations to examine the evolution of farming practices and the impact on farmers' health over time, specifically focusing on the use of wastewater and groundwater for crop irrigation in two distinct areas. It’s worth recognising that scientific research can be investigated using methodologies that delve into the value of how rich that past is. Life History narrations have just proven to be a resource through this research, a hub for information from the most elderly availed with an opportunity to share what they have experienced and how it links to the current happenings.

The use of life history conversations with elders, who are repositories of rich historical information, has revealed that Alaulapur is faced with several health risks that affect farmers, children, and consumers. These risks arise from exposure to physical, chemical, and biological hazards such as unpleasant odours, skin irritants, heavy metals, and microbial pathogens. Those who are directly exposed to irrigation water during farming activities are at the highest risk, whereas consumers who eat contaminated crops face a medium risk of exposure to these hazards. On the other hand, the Lalukheda community enjoys relatively fair and mild health outcomes.

Although the villages share similar characteristics, their farming practices have evolved with the irrigation scheme being the driving factor. At the start of the scheme, the health of the villages was similar. However, changes in irrigation practices over time have had an impact on their health status. The use of wastewater in one village resulted in illnesses, and alcohol abuse was also prevalent due to the poor nutrient status of the community. These incidents have raised concerns about the health implications of effluent contaminants and pathogens entering the soil, potentially reducing crop diversity and affecting farmers' health and crop yields. The village is only able to grow millet, rice, and wheat due to the availability of irrigation wastewater. However, Lalukheda has been able to improve its economic growth and health outcomes by increasing fertilizer use with government subsidies. The availability of diverse crops has positively impacted the health of the villagers. To ensure the long-term effects of wastewater on the environment and end-users are minimised, measures must be taken to restrict the inappropriate disposal of tannery effluent and ensure proper treatment of industrial and municipal effluent. Additionally, proper policies on the reuse of wastewater should be formulated to protect the end-user.

Chapter 6 **Limitations**

This chapter will discuss the challenges encountered during the research process that limited the case study's scope.

- The research proposed to collect data from six target Informants but only managed to get four.
- The research had information limitations regarding health problems as life history respondents declined to share detailed information and felt the topic was a bit sensitive.
- Some respondents could not align past dates for life history.
- There were limitations in collecting secondary information from KII.
- The language used was a hindrance in conveying complete stories and details.

Chapter 7 **Recommendation**

This chapter presents measures to mitigate the long-term health effects of wastewater reuse for farmers and their families.

Recommendation

- It is important to educate farmers and their families about artificial practices that can be used to combat exposure to wastewater and maintain good health such use of PPEs.
- Effluent discharged for irrigation in villages must meet agricultural effluent standards to mitigate health adverse effects.

Future research

- Follow up on emerging information from respondents that villagers died before water source rectification due to contamination, resulting in emerging long-term skin cancer and lung infections.
- It is important to investigate the reasons behind men not seeking healthcare services and try to encourage them to visit health facilities.
- Follow up on the dental tooth decay on mostly men in the village

Chapter 8 **Appendices**

Appendix A. - **Research ethics declaration form**

IHE DELFT Institute for Water Education under the auspices of UNESCO

Research Ethics Committee
IHE Delft Institute for
Water Education
E ResearchEthicsCommitee@un-ihe.org

Date:	2023-07-19
To:	Cuthbert Nkhoma
MSc Programme:	Water and Sustainable Development
Approval Number:	IHE-RECO 2023-cnk002bwa05

Subject: Research Ethics approval

Dear Cuthbert,

Based on your application for Ethical Approval, the Research Ethics Committee (RECO) of IHE Delft RECO gives ethical clearance for your research topic *"Long term changes in wastewater reuse and health, a case study in Kanpur, India."*

This approval is valid until September 30, 2023.

The approval is based on the information submitted in the research ethics application form and endorsed by your mentor or supervisor. The approval of the Ethical Review Board concerns ethical aspects, as well as data management and privacy issues (including the GDPR). It should be noted that any changes in the research design oblige a renewed review by the Ethical Review Board.

Keep this letter for your records and include a copy of it in the final version of your MSc thesis, together with your personal ethics reflection.

On behalf of the Research Ethics Committee, I wish you success in the completion of your research.

Yours sincerely,

Dr. Emanuele Fantini
Coordinator, Research Ethics Committee IHE Delft

Copy to: Archive

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Appendix B. - **Guides for informed consent**

Participant Information Sheet

Dear participant,

I am Cuthbert Nkhoma, an MSc student at the IHE Institute for Water Education. I am working on a research titled*: Long Term Changes in Wastewater Reuse and Health in Kanpur, India*.

Please take time to read through the following information carefully. The aim is for you to be aware of the research purpose and what it involves before deciding to participate in an interview. If you have any questions or would like additional information, please feel free to ask the researcher.

Overview

The research project is a part of the Pavitra Ganga Project, which aims to explore the historical relationship between wastewater reuse and health in villages surrounding the Jajmau municipal wastewater treatment plant.

What have you been asked to do?

I am inviting you to participate in my MSc research study by participating in an anonymous and confidential interview session which will last for around 20 to 45 minutes. The research requires sharing your experience on the development of irrigation schemes and their relationship to the farmer's practices and health. Data obtained from you will be used for the study and will not be shared with anyone outside our project team. Your participation is entirely voluntary, and you are not obliged to be part of the interview. But I hope you will agree to participate since your views are essential. I will share the summary of my findings with you upon completion of the research. In case you need more information on the study, feel free to contact me at;

Contact Information

Cuthbert Nkhoma
MSc. Water and Sustainable Development-Sanitation at IHE- Institute for Water Education.
Westvest 7, 2611 AX Delft/ P.O. Box 3015, 2601 DA Delft
The Netherlands
+31 (0)616652493
cnk002@un-ihe.org

The purpose of the study: is to explore the historical relationship between wastewater reuse and health in villages surrounding the Jajmau municipal wastewater treatment plant in Kanpur, India.

	Please check the box to show your agreement to the following points
I confirm that I have read and understood the information sheet for the above research.	
I have had the opportunity to read the information, ask questions and have these answered satisfactorily.	☐
I agree that my participation is voluntary	☐
I agree that I am free to withdraw at any moment.	☐
I agree that you contact me again to clarify any information.	☐
I consent to have the session recorded and photographs taken.	☐
I agree to take part in the interview.	☐

_______________________________   _______________________________

Name of the Researcher   Date   Signature

If you have any questions or concerns about the research, you can contact me on:

Cuthbert Nkhoma

MSc. WSD-Sanitation at IHE- Institute for Water Education, The Netherlands
+31 (0)616652493
cnk002@un-ihe.org

Appendix C. - Life history and KII guides

A	STP Manager /STP Operator	Alaulapur	Lalukheda
10	When did the irrigation schemes start? Probe: who started? Probe; why did they start? Probe: what were the driving factors?		
2	Do farmers pay for the use of wastewater/water for irrigation? Probe: if so, why probe: when did they start paying?		
3	What channels were being used to supply wastewater/water for irrigation? Probe: have they changed? When did they change, and when?		
4	what type of irrigation methods were being used? When did they start? Probe: have the irrigation methods changed since the inception of the schemes? Probe: if so, when did they change? Probe: how have they changed?		
5	How consistent has the combined wastewater/water discharge been to the schemes over the years? Probe: which period changed? Probe: How Has sludge been used		
B	**Registered Medical Practitioners X 2**		
	Has the health of farmers changed? Probe: Have you observed any specific change in health issues or symptoms among farmers and villagers between Alaulapur and Kalu Kheda? Probe: If so, what are the most common health problems reported? Probe: since when? Probe: who's affected?		
	Are there any known cases linking the use of wastewater/ water in farming to specific health conditions among farmers and villagers? Probe: If yes, could you provide some details on the cases? Probe: prob: when did they start? Probe: why do you think they are a result of the schemes?		
	Can you describe any situation you can relate to children's health because of the kind of water being used in irrigation? prob; frequency of diarrhoea, stunting, (nutrition deficiency) probe: when did they start? Probe: any changes in the health of children who use wastewater for bathing? Probe: since when?		
	What are some of the changes in the health of farmers that have happened in the past? Probe: when did they start? Probe: how do you relate them to the schemes? Probe: How severe are they		

Life history

Target: Narratives on the changes in farming practices and the health of the farmers and villagers in both areas.

- **10 farmers Alaulapur. Life history narratives**

01	Farmer	Alaulapur
	Farming practices • when did the practice of using wastewater start? • why? • Have you been paying for use? • why and since when? • What type of Irrigation methods were being used? • since when and why? • The types of crops which were being grown? • Since when and why? • what has changed, • when did it change and why? Changes in the health of the farmers and villagers, • Any changes in the health of the farmers/ villagers through work or food from irrigation? • how has the experience been? • since when? • What could be the reason? Have there been any unique skin infection experiences? • Who's affected? • Since when and why? Any diarrhoea experienced, • children not growing as expected (malnutrition), • anything strange due to irrigation? • who's affected • why • any accidents as a result of schemes? • Why and since when?	

Farmers Lalukheda. Life history narratives

<table>
<tr><th>02</th><th>Farmer</th><th>Lalukheda</th></tr>
<tr><td></td><td>Farming practices
when did the practice of using groundwater start?
why?
Have you been paying for use?
why and since when?
What type of Irrigation methods were being used, since when and why?
The types of crops grown?
Since when and why?
what has changed,
when did it change and why?
Changes in the health of the farmers and villagers,
Any changes in the health of the farmers/ villagers through work or food from irrigation?
how has the experience been?
since when?
What could be the reason?
Have any unique skin infection experiences?
Who’s affected?
Since when and why?
Any diarrhoea experienced,
children not growing as expected (malnutrition),
anything strange due to irrigation?
who’s affected
why
any accidents as a result of schemes?
Why and since when?</td><td></td></tr>
</table>

Appendix D. - **KII**

K01. Around 1985, the period before the establishment of the treatment plant, the row sewage through drainages was mixed with water from the Ganga River and used for irrigation in the farms along the riverbanks. This practice continued until the treatment plant became operational around 1989. Following its commissioning, the treated sewage was used through the irrigation channels. Initially, these channels were constructed using gravel. However, the Kanpur Metropolitan Council (KMC) later upgraded them to more durable concrete irrigation channels that extended to the village. Farmers rely on the irrigation channel for water with no other options. During the monsoon season, the increased rainfall leads to higher water levels, resulting in a greater volume discharged into the village through these channels. The farmers must pay a small fee to the KMC for accessing this water for irrigation. However, not all farmers comply with this requirement due to its association with land leasing issues. The tannery industry has had a significant and long-standing presence in the area since 1954. By 1986, the number of tannery factories had grown to around 175. There are more than 380 legally registered tannery entities, nearly all releasing their effluent into the common effluent treatment plant (CETP). The quality of effluent from the sewage treatment plant (STP) shows a Biochemical Oxygen Demand (BOD) range of approximately 20-30 mg, discharged into the irrigation channels, indicating a fair discharge into the environment. In contrast, the effluent from the CETP has a higher BOD level ranging from 70 to 100.

K02. In 1952, the Kanpur Development Board began providing irrigation to villages by mixing sewage effluent and Ganga River water. By 1955, a regular water use scheme was launched. The gravel irrigation channel was supplied with water from the Ganga River, which contained essential minerals for crop production. In 1994, Under Ganga Action Plan Phase I, a Common Effluent Treatment Plant (CETP) was established in Jajmau, which changed the composition of water directed to the irrigation channel. The gravel channel no-longer received water from the Ganges but instead received a mix of treated wastewater and tannery effluent with chemicals such as arsenic, and chromium, that caused harm to the fields and crops. The composition of the effluent chemical concentration discharged to the channels would vary depending on the months, with the most highly toxic being November to January.

K03. From 1952 to 1980, farmers in the village used combined Ganga River water with wastewater for irrigation, which never caused health changes among the villagers. From 1985 to 2023, many farmers and villagers who have been attended to indicated an increase in health conditions such as skin rashes, lung infections, dental problems, tumours, and blisters, Dengue virus with a notable prevalence among men. Women who return from fieldwork would unintentionally pass on skin infections to their infants. On average, as a village medical staff, I attend to about 20 skin infections and diarrhoea cases daily. The male population tends to seek medical attention in hospitals outside the village. I have Several men who have developed cancerous gum sores that have been linked to either tobacco use or their work in the field due to the compromised quality of crops grown under tannery effluent; I also see a lot of the villager's children remain prone to recurring coughs, fevers, and bouts of diarrhoea. To safeguard their families during periods of heightened chemical concentration, some farmers enlist additional labour, which unintentionally impacts agricultural production. Generally, the people's health is not very good compared to when we never had this water, but the challenge is that the villagers have no alternative.

k-04. Most people only get to visit for coughs and fever in babies. They have never had severe health problems apart from Covid 19 in 2020. Most farmers with other ailments prefer to buy drugs in town and directly seek services in town and private hospitals. Dental decay in old male persons has been one problem due to tobacco smoke, I would say it's a visible change. I have only attended to farmers who develop rash maybe after spraying the fields with pesticides then they buy tropical applications. generally, their health has been ok.

Appendix E. - Life history narrations

Alaulapur village

A01. I started farming before 1980 using discharged water from the Ganger River mixed with wastewater from the STP. The village didn't have fresh water for irrigation; therefore, due to the caste system, the only option was to use this water to irrigate crops. I initially paid 500rupees per 1acre to the Kanpur municipality for the land given to me, but no payment for the portion I owned until 2022 when I had to contribute to channel maintenance. In 1980, the village was blocked off the fresh water from the Ganger River as the water level became too low, and thus, we could only survive on the wastewater from the STP and, later, the tannery water. The government installed gravel channels in 1980 at the irrigation schemes' inception. This was later improved to concrete canals in 2013. Before 1980, we grew crops such as groundnuts, vegetables, cauliflower and corn, supported with cow dung., but after the 1980s, with the introduction of factor water, only rice and wheat we have been growing. They are the only crops that can withstand the chemicals in the wastewater used for irrigation. We have suffered skin rashes but we are ok.

A02. Before 1950, no special irrigation facility existed; our 12 villages then relied on rainwater for farming. Then came the Kanpur Development Board, which established sewerage and river water mix for irrigation around 1952. The board launched the 1955 Regular Water Use Scheme with wastewater and Ganga River fresh water, allowing it to flow into the village for irrigation; for the past 20 years, I have used wastewater combined with tannery effluent for irrigation. At the start of the scheme, we used to pay 250 rupees for use, but it has now increased to 500 rupees per acre per year. The Kanpur Nega Negam allowed us to use combined effluent to save the Ganga River from tannery effluent contamination and from depleting the fresh water. So, the village was compelled to use the effluent as the only alternative. Hand-dug furrows and gravel channels were built by the Kanpur municipality before 1950. At that time, we could grow all the crops such as corn, sugarcane, cauliflower, onion, and vegetables, but after 1980, STP effluent and tannery effluent were mixed and channelled for use. As a result, skin infections started showing up in everyone who worked on the farm. After 1990, the effluent became too contaminated to grow crops such as beans, corn, vegetables, etc., and only wheat, millet, and rice could survive the chemicals.

A03. In 1952, the Kanpur Municipal Corporation (KMC) set up a plant where sewage was collected and meant for us. Before 1950, shallow-well water was used to irrigate crops such as beans, corn, wheat, and rice for personal consumption. After 1952, some people from the countryside captured the land and started using wastewater for their farms. At this time, the government was not aware. We used water buffalos and cattle traditional land preparation methods from 1950 till 2003. In 2003, factory effluent was mixed with sewerage in the same channel and was delivered to the village. Villagers protested against receiving combined wastewater and proposed to the government to remove the plant location to another town. In 2015, the chemical composition in the combined wastewater became too high, and the Kanpur municipality continued disposing into the drains of the villages, assuming the villagers were not aware of the effects of the water. This has continued from 2003 to date. Skin diseases have manifested in everyone who works on farms. Because of high contamination, drinking water handpumps are installed from 150 ft to 200ft depth to reduce high-level chemical contamination. Between 2003 and 2013, the effluent quality was less chemicals, but after 2013, the chemicals increased. Because of high contamination, only wheat and rice have been grown since 2003. Oxcarts with buffalos were used to cultivate land but were changed to tractors in 2013 due to much time needed. Further, the volume of water channelled to the farm has been high. Therefore, much energy through the tractor is required.

A04. Before 1950, the British Empire ruled India. It made separate basements from the high land areas to the village and set up sewage plants for effluent flow, with little Ganga river water mix flow for irrigation into the village. In 1975, Tannery effluent was allowed to mix with sewerage because it had nowhere to go in reducing the contamination of the Ganga River; in 1980, Ganga River water stopped being added to the mix as government policy. Since then, only tannery and STP effluent have been used. Since 1950, gravel channels have existed, and concrete channels were built by the government in 2013. From 1952 to 1995, crops grown included corn, sugarcane, vegetables, and cauliflower; after 1995, the roots of crops were getting weaker with the effect of tannery effluent and therefore stopped and changed to wheat and rice till now. Since 1950, we started paying for the use of wastewater, which has been increasing every four years, starting from 36 rupees in 1952. From 2013 till now, we have been paying 1050 per year per acre of land. Regarding health, before tannery effluent was introduced, there were no skin infections or liver problems. After introducing tannery effluent, the government protected its face by ensuring all sick people were prescribed medicines to return to villages, but they never recovered. Skin infections usually resolve themselves. From 1995 to 2004, Four farmers developed cancers from exposure to the water on swollen legs and blisters. Two died, and two others are still alive; they believed these illnesses were caused by water because the concentration was too strong of the chemicals. Through awareness, they stopped using the most contaminated water in the reservoir.

A05. In 1997, wastewater was allowed for irrigation with tannery effluent to protect fresh water from the Ganga River, which was becoming scarce. The land was allocated for cultivation with no tax for irrigation water to farmers, but for the land given by the Kanpur municipality, the village people had to pay tax. From 1952 to 2003, farmers had been cultivating land using buffalos and oxcarts. In 2003, the animals were replaced with efficient tractors, and they could get them on hire for an hour, 700 rupees. Before 1995, they could grow all crops, such as bananas, watermelons, okra, cauliflower, and corn. After 1995, I stopped and concentrated on paddy and wheat. This was after observing for two months the crops not growing. They tried to grow other crops, but the land could not withstand the chemicals in the effluent. In 1995, most people started experiencing skin diseases due to the tannery effluent use and the time spent in the field, which had high concentrations. Some started having round warms and eventually had blister patches that could not go away on the skin. The family's lives haven't been so good as mostly rashes and diarrhoea are the order of the day.

A06. From 1980, Ganga river water and wastewater were used for crops in the village farms. In 1990, tannery effluent was allowed to mix with sewage from the STP. However, before 1980, few tanneries releasing chemicals existed. After 1990, more than 100 tanneries were put up, increasing chemical concentration and discharge volume. we decided not to pay for personal land tax as the only available water for them to use for cultivation. In 1950, gravel channels were constructed by the government. In 1995 summer, stones were put in gravel channels with sand. In 2013, concrete channels were made for the same length as the gravel channels. Before 1990, farmers were growing all crops. After 1990, we grew only wheat and rice because there was no water management system; crops were submerged due to the high volume of combined effluent discharged to the village and remained stunted. Hence, we changed to rice and wheat. Around 2003, we observed tasteless rice and wheat grown. The main complaint for all working on the farms has been skin infections from when tannery effluent was allowed to be used in the farms around 1990.

A07. We started farming before 1950, using rainy water for the fields. In 1985, tannery effluent was allowed with sewage effluent for irrigation in the village farms. Before 1985, we could grow all crops with seasonal water and use pesticides and urea, including cow dung. After 1985, due to huge volumes of effluent, crops could not grow; only wheat and rice could grow because huge volumes of water were discharged into the village, flooding the crops. In 2000, a water survey was conducted, and it revealed that about 80ft of water is polluted and is not to be used, increasing further water scarcity for drinking in the village. Before 2000, using buffalos and cows. After 2000, cultivating the land using a tractor has been efficient. Large acres of land are attended to and proved cheaper even in not providing more animal food, less cost for tractor hire for an hour. Before 1985, gravel channels were maintained by the government for 26 villages. After 1985, channels were not extended but concretised. Before 1985, Water bone diseases were less common. After 1985, villagers experienced high levels of malaria, and skin rash increased, affecting working time.

A08. Before 1988, irrigation and farming were okay with rainwater, Ganga river water and wastewater mix. After 1988, farmers started using wastewater and tannery water; two years later, in 1990, after observing skin infections, all farmers requested to test the water and soil with the introduction of combined wastewater and tannery effluent. The test revealed too much chromium in the ponds used as reservoirs for irrigation water. The reservoir ponds in the village were developed in 1945. however, no change was made to channelling mixed water to the village. Gravel channels were constructed in 1955, and concrete channels in 2013 to distribute irrigation water to the farms centrally. After 1995, they stopped growing other crops, such as flowers, mangoes, and corn, due to chemicals in the water and the high-water level. Before 1995, they used buffalos and oxcarts to dig land to reduce cultivation time. In 1995, we changed to Tractor for easy and fast land cultivation." My father developed gum cancer, and from 1995, 45 persons in the village were infected with skin, gum cancers, and liver problems from mixing food with tannery chemical effluent interaction in the field. From 1995 to 2021,20 people allegedly died from long-term exposure effects to working in farms with tannery effluent, and these cancers started manifesting between 2015 and 2021. Farmers observed excess chemicals every year between March and April for winter and December and January. The crops have helped us to survive, but the yield is not very good.

A09. Before 1984, the Ganga River and STP wastewater were used for irrigation. After 1984, wastewater and tannery effluent were used for irrigation to grow crops. Before 1975, only 14 villages existed, and water buffalos and oxcarts were used to cultivate the land. In 1997, farmers changed to tractors, which were seen to reduce the land preparation time. Around 1975 water level was too low in the fields, and thus, they could grow all crops, millet and groundnuts. After 1975, the management system for discharging irrigation water became worse, and they could only grow wheat and rice due to the high-water level. The water management system needed to be better. Around 1997, the farmers used conventional fertilisers such as urea 1997. After 1997, we stopped using fertilisers as chemicals were assumed to have enough urea in the irrigation water composition. Limited common illnesses were experienced in terms of health, such as fever, cough and diarrhoea, before tannery water. However, the chemical composition became too high, and hence no insects or snakes in the water could survive, it's the reason we also don't use pesticides because we feel it's waste as the chemicals are usually too strong. After introducing tannery water, we have seen an increase in skin infections, fever and coughs.

Lalu Kheda Village

L01. Around 1980, we started farming using rainwater, and in 1990, we changed and began to use BH water with the submersible pumps we had bought. It was diesel propelled- and operated from 1993 to 2013, changed to electric pumps in 2013 due to an increase in the cost of diesel. Due to the unpredictable weather and the variety of crops, we needed to grow throughout the year. The government supported us with the installation of electricity for further reconnection of the BH. Before 2013, we used dug wells to move water into the furrows. After 2013, we started using pipes connected to the electrical submersible pumps. About ten (10) families use one Borehole and connect their polylines to their farms one hour per day and only pay for electricity. It has kept changing year by year from 450 rupees in 2013 to 500rupiess per year today. We have been growing all crops, such as watermelons, cucumber, okra, pumpkins, and rice, in the last 45 years because water is pure and can support seasonal crop rotation. From 1980 to 1998, we used cow dung to support crop growth. From 1985 to 1997, buffalos were used for cultivation but they needed to be more efficient and affordable. In 1997 changed and started using tractors to cultivate the land, which has been more efficient and cost-effective. Changes in the health of the farmers, everyday health lives and normal health fevers have been experienced with little concern.

L02. In 2009, I started farming. I picked it up from my father. I have been using a tractor for cultivation. In 2009 I used to pay 200rupiies per hour rent, which has changed to 900 rupees per hour. Further, I used a diesel-propelled submissive pump from 2009 to 2017, then switched to an electric pump. We use gravel irrigation channels for channelling water to the farm. From my inception of farming, I only used cow-dang for one year in 2012, which was spread on the farmland; after 2012, I have been using sustainable, available and cheaper fertilisers. Depending on the season, I have been growing all crops on a rotational basis: Monsoon rice and wheat, and the other seasons for much support with only irrigation water for pumpkin, cucumber, and okra. The changes in health have yet to be observed because we have lived the same lives, except when we have monsoons and stagnant water, we have malaria.

L03. From 1983 to 1993, I farmed with shallow well water for rice and other crops. I used rainwater for monsoon seasons and a ground tank to store water through irrigation furrow channels using water cans. In 2008, I started using diesel engines for irrigation. In 2013, I moved to electricity pumps due to the expense and the high cost of irrigating a large area. The government has not been involved. Everything has been personal. The government has provided subsidy services like tractors and submersible pumps for those with money to buy over time. As a farmer, I used a personal oxcart from 1983 till 2019, but too much feed was needed for the animals, and I changed to renting tractors until now. I have since sold the oxcart. From 1983 to 2021, I used cow dung to mix with fertilisers and spread on the land. From 2021, I had to reduce the level of cow dung because of access, and hence the need for more fertilisers. Between 1983 and 1993, few people used to get sick, but now a good number of people have ailments whose source is unknown, ailments such as coughs and flu.

L04. I started farming in 2005, made a channel and used a diesel engine to collect water. From 2005 to 2017, then changed to electrical until today. A payment of electrical charge pay hour is charged. The channels have remained gravel. All crops are being grown, and in 2015, flowers were grown on my farmland. My family has been having what could be described as normal health, just fever and coughs. I am still using cow dung and fertilisers for the fields, depending on the availability of cow dung. I was using animals and changed in 2002 for quick cultivation. When starting, I had to hire a tractor at 200 per hour, now 800 per hour.

L05. Since 2012, I have been getting water from a well and connected a diesel engine to pump water till now. In 2015, I started using the electrical pump and from 2012 to 2019, I used an oxcart, and then the tractor was rented till today. I have been paying depending on the land to be cultivated. Around 2012, I started using cow dung, but it's been limited due to scarcity. Hence, the incorporation of chemicals. Lately, I have been using pesticides to spray on crops and assume that a few cases of flu and coughs have originated from the chemicals. Previously, my family used to be very healthy with the food produced, thinking the crops grown with fertilisers, but the kids were not as strong as they were in his time.

L06.I started farming in 2008. I was using a tractor, which I hired at 200 rupees per hour to cultivate my land, and now paying 900. From 2009 to 2017, I used diesel to run a submersible pump engine, which proved expensive; I changed the electric supply in 2017. However, we have had to revert to the engine when the electricity is interrupted. The borehole is personal and drilled by myself. One submersible borehole for about ten families and irrigation channels were furrowed. I used to Spread cow dung on the land and used the same pesticides for crops. Fertiliser has been used and proved cheaper than cow dung; urea was sprayed two times,2.5

acres of land 50kg on crops such as flower, watermelon, cucumbers, and okra. I have been growing wheat and rice at the seasonal level to warrant adequate water available. The changes in my family's health, yes, I can describe it as everyday l sicknesses such as fevers, flu and coughs; however, today, back pains are the most common, and we go to the hospital for check-ups.

L07. From 1978, I started farming using shallow-well water for five years and changed to a diesel engine from 1984 to 2013. In 2013, I moved to an electrical pump because electricity became cheaper. The pumps have been affordable; the village has 140 HH who share the 13 existing boreholes. The farmers in the village use gravel channels supported with plastic pipes to drain water into their fields for an hour. I have been growing pumpkins, flowers, and okra. I was the first flower farmer, and I started in 2003 because of the profit margins from the cultural value of flowers in the country. The community has had no unusual illness apart from headaches and fever. The changes cannot be observed, but economically, we have grown to have a healthy community that doesn't get sick easily. They used to have dengue fever around 2011 and since then stopped; also, diarrhoea was being experienced, and Some recently developed kidney failure problems in adults. 2013 till date, using tractors; before that, cows and buffalos with oxcarts for the cultivation of land were renting tractors for an hour 500 rupees from 200 in 2013. I have also been using cow dung from 1978 to 1985 only because fertiliser had yet to be introduced into the village, then started using fertiliser from 50 and now use 25kg. He has reduced cow dung use because it's not readily available in the field.

L08. Started in 1973, have been using a submersible pump to grow all crops, such as pumpkin and rice, and a hired tractor to cultivate the field. The crops have been growing without challenges, such as flowers, 2003, beans, rice, millet, wheat, chilli, corn, and watermelon, and we connect our pipes to the communal bole hole and pay monthly contributions. I have a long pipe that supports my crops. Since 1985, I have used both cow dung and fertilisers but mostly cow dung.2015, from using pipe but have been using gravel channels in the field.no family’s health issues in the family from 1978 till date. I used chemicals to spray on crops but still managed my prevention.

LH9. I started farming in 2003. I used to irrigate my crops using a diesel engine until 2015, paying 500rupees per month, and it's now 1600 per month. I had to change to an electrical pump due to the limited horsepower from the diesel engine that could not support pumping at a high water depth. Furthermore, from 2003 to 2016, I used gravel channels to irrigate crops, and then I installed pipes for boreholes to take water into the field. I have been growing okra, beans, peanuts, rice and wheat from 2003 to 2018. I have also been using cow dung, and eventually, it’s been difficult to access cow dung, resulting in buying fertilisers, starting with 50kg of fertilisers. I grew and still wheat in March and rice in June. Regarding health problems, stomach pains and diarrhoea have been part of us, including fevers, and most people have taken them as normal. People around the village have tooth problems due to too much tobacco men consume.

L010. I started farming in 1998 using a diesel engine pump for irrigation, which was personal. In 2013, I switched to electrical pumping of water, which has been seen to be cheap for a large area of land to cultivate 1998 to 2013, I used gravel channels and joined pipes to connect water for the fields. 1998 till 2001 used oxcarts till now, renting from a farmer with resources. I was paying 500 rupees per hour, having been growing all crops, wheat rice, beans, cucumber and millet, only the problem of teeth rotting due to tobacco intake and a skin rash with diarrhoea. Their lives have changed because they have to go to town to check on medication unless previously they would be checked on by a local doctor.

Appendix F. - **Changes in farming practices**

Alaulapur village- overview of respondents

S/N	Similarities	Differences
1	Using irrigation channels for water distribution is common, and transitioning from gravel to concrete channels for irrigation water distribution aims for better efficiency and maintenance.	The specific details of tax payments vary, with different rates and changes in price over time (A-01, A-04, A-07, A-09).
2	Farmers pay taxes to the Kanpur Municipality for their land use. The tax amount and payment frequency vary over time.	The years when the transition from animal-powered methods to tractors occurred differ across many farmers, ranging from 2003 (A-03) to 1997 (A-09).
3	There's a transition from traditional animal cultivation methods to tractors, adopted as more efficient and time-saving methods for land cultivation, replacing traditional animal-powered methods.	The approach to using fertilisers differs, with some farmers mentioning a shift from traditional fertilizers to relying on chemicals already present in irrigation effluent. (A-09).
4	For most farmers, the introduction of tannery effluent and STP wastewater significantly impacted the types of crops that could be grown. Wheat, rice, and millet were generally the only crops that could survive the high level of chemical composition for the irrigation water.	While all farmers mention constructing irrigation channels, the years when gravel and concrete channels were built vary (A-01, A-06, A-08).
5	Most farmers mention challenges related to water management, including high water levels, flooding, and lack of proper water management systems, which affect crop growth.	The timeline of changes from regular crops to wheat and rice varies across farmers. Some farmers show a shift starting around 1980 (A-01, A-02), while others mention differences in the 1990s (A-06, A-08) or even earlier (A-09, A-03).

Lalukheda village- overview of respondents

S/N	Similarities	Differences
1	There's a noticeable shift from traditional methods (like using animals and manual labour) to modern machinery (such as tractors and electrical pumps) for cultivation and irrigation.	Farmers' approaches to soil nutrition vary. Some (L-01, L-03, L-04, L-05, L-06, L-07, L-08, L-09) emphasise the historical use of cow dung for soil fertilisation, while others (L-02, L-03, L-05, L-06, L-09) shift to commercial fertiliser and challenges in cow dung access lead to reduced usage for some (L-03, L-05, L-09).
2	There's a consistent mention of changing costs in equipment rental and input expenses like electricity and fertilisers. These costs have generally increased over time.	Some farmers (L-03) mention government subsidies for tractors, while others rely on personal efforts (L08), showing diverse strategies. Farmers differ in water sources, with some using private boreholes or wells (L-01, L-02, L-05, L-08) and others relying on communal sources or boreholes (L-08, L-10, L-09). Cost changes also vary, including hourly tractor rental rates (L-02, L-05, L-07) and fluctuations in electricity expenses (L-01, L-03).
3	Farmers in the village have moved from relying on dug wells and animal-driven systems to using electrical submersible pumps and pipes for irrigation. Gravel irrigation channels are also a standard feature.	The farmers L-04 and L-07 explore the art of flower cultivation, with L-07 emphasising its immense profit potential.
4	All farmers mention growing various crops, including watermelon, cucumber, okra, pumpkins, rice, wheat, flowers, beans, peanuts, and millet. Several farmers (L-01, L-02, L-04, L-06, L-07) discuss rotational cropping, where different crops are grown in different seasons for optimal utilisation of resources. Some farmers mention Monsoon rice and wheat as seasonal crops (L-02, L-06).	While water availability is not discussed in all sections, L-01 highlights the availability of pure water for crop rotation, and L-08 mentions the shift from pipes to gravel channels for irrigation.
5	Cow dung has been a common source of fertiliser in many sections, and over time, some farmers have shifted towards using commercial fertilisers due to non-availability.	Farmers' approaches to soil nutrition vary. Some (L-01, L-03, L-04, L-05, L-06, L-07, L-08, L0-9) emphasise the historical use of cow dung for soil fertilization, while others (L-02, L-03, L-05, L-06, L-09) shift to commercial fertiliser and challenges in cow dung access lead to reduced usage for some (L-03, L-05, L-09).

Appendix G. - **Changes in the health**

Alaulapur village- farmers' views

S/N	Similarities	Differences
1	Skin infections are a recurring health issue among those who work in the fields across all sections (A-02, A-03, A-04, A-05, A-06, A-07, A-08, A-09).	In the past, villagers experienced common health issues like fevers, diarrhoea, and malaria (A-02). After the introduction of tannery water, fever and coughs increased (A-09). Certain farmers (A-04, A-08) mention cancer, including gum, skin, and liver cancers, allegedly linked to exposure to tannery chemical water.
2	Tannery water is a common cause of skin infections in several sections (A-04, A-05, A-06, A-08, A-09).	Skin infections, cancers, and other health problems have manifested at different times, ranging from the 1990s to 2021 (A-04, A-08).
3		For some farmers, awareness about water contamination led to changes in water usage practices (A-04) through PPE usage and avoiding certain waters.

Lalukheda village -farmers' views

S/N	Similarities	Differences
1	All farmers mention health issues, including fevers, coughs, flu, diarrhoea, skin rashes, tooth problems, and back pains.	Some farmers (L-01, L-02, L-04, L-05, L-06, L-08, L-09) describe a normal or healthy life history with occasional fevers or common illnesses.
2	Many farmers note changes in health conditions, ranging from relatively mild or common ailments to more severe concerns.	For L-03, an increase in ailments like coughs and flu is noted, with an unknown source. L-06 mentions back pains becoming more common over time.
3		L-07 observes a healthier community with economic growth but mentions dengue fever, diarrhoea, and kidney failure as past issues.
		L-09 highlights tooth problems due to tobacco consumption by men.
		L-08 mentions using chemicals for crop spraying but maintaining family health.
		L-10 notes change in healthcare access, with people needing to travel to town for medication instead of relying on a local doctor

Appendix H. - **Timeline of events**

Evolution of events in Alaulapur and Lalukheda villages

Alaulapur

	1950s	1960s	1980s	1990s	2000s	2010s
HEALTH	• only Common illnesses, fevers, diarrhoea, and malaria.		• The introduction of tannery effluent for irrigation led to skin infections among farm workers, which was previously uncommon	• Health was poor, with less food available. • Babies get affected by skin conditions by their mothers • An increased number of eye infections, liver problems and hair turning grey for farm workers.	• Men not seeking health services • Increase in Skin diseases, roundworms, blister patches, rashes, dental problems and diarrhoea became prevalent due to high chemical concentrations in irrigation water • Cases of lung problems cancers, Skin infections, gum cancers, and liver problems were reported, resulting in deaths.	• Increased dental decay, tobacco intake and alcoholism
FARMING PRACTICE	• Diverse crops were grown, including groundnuts, vegetables, corn, cane, millet, rice, watermelons, okra, chilli, and wheat. • Farmers fertilised their soil with cow dung. • Farmers used cattle and water buffalos for land preparation/ cultivation practices.	• Most farmers didn't use any organic supplement for soil as the wastewater already had nutrients. • Introduction of wastewater usage for irrigation at a minimal fee.	• Started using conventional fertiliser for soil fertility • The introduction of factory effluent and tannery water for irrigation led to a shift to mainly rice, millet and wheat cultivation	• Farmers stopped using conversational fertiliser • Farmers started using tractors for irrigation	• Limited crops grown, only wheat, millet and rice.	
SCHEME DEVELOPMENT	• Farmers relied solely on rainwater for irrigation. • The Kanpur Development Board introduced sewage effluent and Ganga River water mix for irrigation. • A regular water use scheme was launched, allowing the mix to flow to the villages.	• Gravel channels constructed for better water distribution through government support. • The gravel irrigation channel was supplied with water from the Ganga, which carried essential minerals for crop production.	• Ganga Action Plan Launch Phase I, a Common Effluent Treatment Plant (CETP) was established in Jajmau. • Farmers were meant to utilise wastewater from STP combined with tanner effluent for irrigation	• In 1995 summer, stones were put in gravel channels with sand.	• Over 100 tanneries were built, leading to higher chemical concentration and discharge volume. • Irrigation water was tested after introducing combined wastewater and tannery effluent in the village. • Water survey conducted, for Boreholes less than 80ft depth, water is polluted and is not to be used for drinking water.	• Gravel drainage channel improved to concrete.

Lalu Kheda

	1950s	1960s	1980s	1990s	2000s	2010s
SCHEME DEVELOPMENT	• Farming was done using rainwater and shallow well water • Farmers began using diesel engines to irrigate newly expanded land with water from shallow wells.			• began to use borehole water with submersible pumps • Farmers started drilling Boreholes and could connect the diesel engines for irrigation through the gravel furrows.	• Farmers have been using poly pipes to connect submersible pumps for one-hour daily irrigation of crops	• Electricity was introduced in the village
FARMING PRACTICE	• Most farmers relied on cattle and water buffaloes to cultivate their land. • Sustainable Practices, practised rotational crop cultivation, growing all crops based on the season.			• Transition to using sustainable and available fertilisers due to limited cow dung access and seasonal and Diverse Cultivation. • Some farmers introduced pesticides to support crop growth	• Adoption of electrical submersible pumps and pipes for irrigation, leading to more efficient water distribution. • Introduced plastic poly pipes for farm irrigation • Gradual shift from animal-based cultivation to machinery-based using tractors.	• 2013 payment for electricity use • Growing all crops on the market such as flowers
HEALTH	• An increase in ailments like coughs, flu, and other unknown sources of illnesses was observed.				• Dental and respiratory Issues: Some health issues, such as tooth problems and respiratory infections, were observed, potentially linked to tobacco consumption and pesticides • Many individuals reported relatively stable health conditions, with mild fevers and occasional illnesses like coughs and flu. • Some noted differences in children's health, indicating potential changes in food quality or environmental factors.	• The health of farmers improved after less work in the field to cultivate and more land, which meant more produce. • The introduction of electricity meant more crops were grown, and a variety of food consumption was available to support health.

Appendix I. - **Personal declaration**

I, Cuthbert Nkhoma, hereby declare that the results and analysis presented in this report for the thesis titled "Long term changes in wastewater reuse and health, a case study in Kanpur, India" were compiled by me. I designed my research with the help of my mentor and supervisor. The Pavitra Ganga India/EU Project provided aid through financial support towards accommodation, travel, and other vital logistics necessary for the research. I designed my study to explore how the novel technology reuse scheme of wastewater along the banks of the Jajmau STP impacts the long-term effects on farming practices and their health.

This thesis is my research work and has not been published anywhere. Therefore, it precisely reflects the findings and analysis of my research study. Any ideas taken from other authors have been appropriately acknowledged and referenced. Various contributions from other authors and papers reviewed support this research. I have further made many improvements within the confines of ethical consideration guidelines. I am a firm believer in upholding the ethical values of an institution that shall confer on me the degree upon graduation.

I used a mixed method to obtain data from the field through key informant interviews (KII) and the participants' life histories. These are viable methods which other interested researchers can use. I worked with a research assistant during the data collection. I trained the assistant through the data collection protocols. I took notes and recorded the conversations. I provided the interview guide to the translator to ensure a smooth flow of the interviews from Hindi to English. I applied the knowledge gained from the study period in practice, which has helped improve my understanding of sanitation and research practices. I used secondary data gathered from publications that are from trustworthy sources and with proper referencing.

I developed this thesis under Dr. Claire Furlong's mentorship and Prof. Tineke Hooijmans Supervision. I kept the subjects' identities anonymous by using codes. I did not Manipulate the results and followed all grammar rules to discuss the results to the best of my knowledge. I declare no conflict of interest. With this, I certify that I wrote this.

Chapter 9 **Reference**

Amerasinghe P, Bhardwaj RM, Scott C, Jella K, Marshall F (2013) Urban wastewater and agricultural reuse challenges in India IWMI

Angelakis A, Bontoux L (2001) Wastewater reclamation and reuse in Eureau countries. Water Policy 3: 47-59

Angelakis AN, Asano T, Bahri A, Jimenez BE, Tchobanoglous G (2018) Water Reuse: From Ancient to Modern Times and the Future. Frontiers in Environmental Science 6 DOI 10.3389/fenvs.2018.00026

Asano T, Burton F, Leverenz H (2007) Water reuse: issues, technologies, and applications McGraw-Hill Education

Babalola FM, Breitenmoser L, Furlong C, Campling P, Hooijmans CM (2023) Occupational Health Risk Assessment for Wastewater Treatment and Reuse in Kanpur, India. International Journal of Environmental Research and Public Health 20: 6072

Bakar N, Abdullah MYH (2008) The life history approach: fieldwork experience. Journal e-Bangi 3: 9

Bassi N, Kumar MD (2012) Addressing the civic challenges: perspective on institutional change for sustainable urban water management in India. Environment and Urbanization Asia 3: 165-183

Beuchat LR, Ryu JH (1997) Produce handling and processing practices. Emerg Infect Dis 3: 459-465 DOI 10.3201/eid0304.970407

Blumenthal UJ, Peasey A (2002) Critical review of epidemiological evidence of the health effects of wastewater and excreta use in agriculture. unpublished document prepared for World Health Organization, Geneva, www who int/water_sanitation_ health/wastewater/whocriticalrev pdf

Board ICPC, Division ICPCBP (2010) Status of Water Supply, Wastewater Generation, and Treatment in Class-I Cities & Class-II Towns of India Central Pollution Control Board, Ministry of Environment and Forests …

Bradford A, Brook R, Hunshal CS (2003) Wastewater irrigation in Hubli–Dharwad, India: implications for health and livelihoods. Environment and Urbanization 15: 157-170 DOI 10.1177/095624780301500206

Breitenmoser L, Cuadrado Quesada G, N A, Bassi N, Dkhar NB, Phukan M, Kumar S, Naga Babu A, Kierstein A, Campling P, Hooijmans CM (2022) Perceived drivers and barriers in the governance of wastewater treatment and reuse in India: Insights from a two-round Delphi study. Resources, Conservation and Recycling 182: 106285 DOI https://doi.org/10.1016/j.resconrec.2022.106285

CHAKRAVARTI AK (1973) Green revolution in India. Annals of the Association of American Geographers 63: 319-330

Cherfi A, Achour M, Cherfi M, Otmani S, Morsli A (2015) Health risk assessment of heavy metals through consumption of vegetables irrigated with reclaimed urban wastewater in Algeria. Process safety and environmental protection 98: 245-252

Cordell D, Drangert J-O, White S (2009) The story of phosphorus: global food security and food for thought. Global environmental change 19: 292-305

CPCB (2021) National Inventory of Sewage Treatment Plants. Retrieved from

CPHEEO G (2013) Manual on sewerage and sewage treatment systems Ministry of Urban Development New Delhi.

Deshpande T (2017) State of agriculture in India. PRS Legislative Research 53: 6-7
Drexler ILC, Prieto AL, Yeh D (2014) 3.2 - Wastewater Constituents. In: Ahuja S (ed) Comprehensive Water Quality and Purification:7-29.
Feachem RG, Bradley DJ, Garelick H, Mara DD (1983) Sanitation and disease: health aspects of excreta and wastewater management John Wiley and Sons
Flick U (2017) The Sage handbook of qualitative data collection Sage
Flowerdew R, Martin D (2005) Methods in human geography: a guide for students doing a research project Pearson Education
Gathorne-Hardy A (2016) The sustainability of changes in agricultural technology: The carbon, economic and labour implications of mechanisation and synthetic fertiliser use. Ambio 45: 885-894 DOI 10.1007/s13280-016-0786-5
Gautam PV, Mansuri SM, Prakash O, Pramendra, Patel A, Shukla P, kushwaha HL (2023) Agricultural Mechanization for Efficient Utilization of Input Resources to Improve Crop Production in Arid RegionEnhancing Resilience of Dryland Agriculture Under Changing Climate: Interdisciplinary and Convergence Approaches:689-716.
Gulati A, Juneja R (2020a) Farm mechanization in Indian agriculture with focus on tractors. ZEF-Discussion Papers on Development Policy
Gulati A, Juneja R (2020b) Farm mechanization in indian agriculture with focus on tractors. ZEF Discussion Papers on Development Policy 297. Center for Development Research (ZEF), Bonn https://doi org/102139/ssrn 3689250
Gupta M, Ravindra V, Palrecha A (2016) Wastewater irrigation in Karnataka: an exploration. IWMI-Tata Water Policy Research Highlight
Gupta N, Khan D, Santra S (2009) Prevalence of intestinal helminth eggs on vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. Food control 20: 942-945
Gupta UC, Gupta SC (1998) Trace element toxicity relationships to crop production and livestock and human health: implications for management. Communications in Soil Science and Plant Analysis 29: 1491-1522
Gutterres M, de Aquim PM (2012) Wastewater reuse focused on industrial applicationsWastewater Reuse and Management:127-164.
Hossini H, Shafie B, Niri AD, Nazari M, Esfahlan AJ, Ahmadpour M, Nazmara Z, Ahmadimanesh M, Makhdoumi P, Mirzaei N, Hoseinzadeh E (2022) A comprehensive review on human health effects of chromium: insights on induced toxicity. Environmental Science and Pollution Research 29: 70686-70705 DOI 10.1007/s11356-022-22705-6
Hurdalkova LT, Kuta D, Zdrazilova N (2016) Diagnostics of the Influence of Suspended Solids and Phosphorus on Groundwater QualityEnvironmental Science and Sustainable Development: International Conference on Environmental Science and Sustainable Development (ICESSD 2015) World Scientific, pp. 149-154.
Hussain MI, Muscolo A, Farooq M, Ahmad W (2019) Sustainable use and management of non-conventional water resources for rehabilitation of marginal lands in arid and semiarid environments. Agricultural water management 221: 462-476
Jaramillo MF, Restrepo I (2017) Wastewater Reuse in Agriculture: A Review about Its Limitations and Benefits. Sustainability 9: 1734
Jiménez B (2006) Irrigation in developing countries using wastewater. International Review for Environmental Strategies 6: 229-250
Kanpur Nagar Nigam (2006) Final Report: Kanpur City Development Plan Under JNNURMhttps://kmcupnicin/JNNURMaspx.
Kaur R, Wani S, Singh A, Lal K (2012) Wastewater production, treatment and use in IndiaNational Report presented at the 2nd regional workshop on Safe Use of Wastewater in Agriculture, pp. 1-13.

Kesari KK, Soni R, Jamal QMS, Tripathi P, Lal JA, Jha NK, Siddiqui MH, Kumar P, Tripathi V, Ruokolainen J (2021a) Wastewater treatment and reuse: a review of its applications and health implications. Water, Air, & Soil Pollution 232: 1-28

Kesari KK, Soni R, Jamal QMS, Tripathi P, Lal JA, Jha NK, Siddiqui MH, Kumar P, Tripathi V, Ruokolainen J (2021b) Wastewater Treatment and Reuse: a Review of its Applications and Health Implications. Water, Air, & Soil Pollution 232: 208 DOI 10.1007/s11270-021-05154-8

Khai HV, Yabe M (2012) Rice yield loss due to industrial water pollution in Vietnam. Journal of US-China Public Administration 9: 248-256

Koshy J (2018) More river stretches are critically polluted: Central Pollution Control Board. Hindu 17

Kumar MD, Tortajada C (2020) Assessing wastewater management in India Springer

Lerner AM, Eakin H (2011) An obsolete dichotomy? Rethinking the rural–urban interface in terms of food security and production in the global south. The Geographical Journal 177: 311-320

Lofrano G, Brown J (2010) Wastewater management through the ages: A history of mankind. Science of the Total Environment 408: 5254-5264

Massoud MA, Kazarian A, Alameddine I, Al-Hindi M (2018) Factors influencing the reuse of reclaimed water as a management option to augment water supplies. Environmental Monitoring and Assessment 190: 531 DOI 10.1007/s10661-018-6905-y

Mcghee T (1991) Water Supply and Sewerage. McGraw-Hill. Inc ISBN 0-07-060938-1

McMahon G, Shaw R (2019) The F Diagram (Portrait version) Loughborough University.

McNamara LA, Martin SW (2018) 1 - Principles of Epidemiology and Public Health. In: Long SS, Prober CG, Fischer M (eds) Principles and Practice of Pediatric Infectious Diseases (Fifth Edition):1-9.e1.

Metcalf L, Eddy HP, Tchobanoglous G (1991) Wastewater engineering: treatment, disposal, and reuse McGraw-Hill New York

Minhas P, Samra J (2004) Wastewater use in peri-urban agriculture: impacts and opportunities. Wastewater use in peri-urban agriculture: impacts and opportunities

Minhas PS, Saha JK, Dotaniya ML, Sarkar A, Saha M (2022) Wastewater irrigation in India: Current status, impacts and response options. Science of The Total Environment 808: 152001 DOI https://doi.org/10.1016/j.scitotenv.2021.152001

Mishra S, Kumar R, Kumar M (2023) Use of treated sewage or wastewater as an irrigation water for agricultural purposes- Environmental, health, and economic impacts. Total Environment Research Themes 6: 100051 DOI https://doi.org/10.1016/j.totert.2023.100051

Mukherjee S, Chakraborty S, Sur S, Ahmad MI, Guin A (2015) Urban waste water: Treatment & re-use: A theoretical perspective. Journal of Basic and Applied Engineering Research 2: 1255-1259

Narayanamoorthy A (2006) Potential for drip and sprinkler irrigation in India. Draft prepared for the IWMI-CPWF project on ‘Strategic Analysis of National River Linking Project of India

Okem AE, Odindo AO (2020) Indigenous Knowledge and Acceptability of Treated Effluent in Agriculture. Sustainability 12: 9304

Oron G, DeMalach Y, Hoffman Z, Manor Y (1992) Effect of effluent quality and application method on agricultural productivity and environmental control. Water Science and Technology 26: 1593-1601

Parveen T, Hussain A, Someshwar Rao M (2015) Growth and accumulation of heavy metals in turnip (Brassica rapa) irrigated with different concentrations of treated municipal wastewater. Hydrology Research 46: 60-71

Pavitra Ganga (2020) http://www.pavitra-ganga.eu/en/demonstration-sites/kanpur-jajmau-wastewater-treatment-plant

Pavitra Ganga ("n.d") *Pavitra Ganga EU/India Project baseline Survey data* IHE Delft Institue for Water Education.
Pedrero F, Kalavrouziotis I, Alarcón JJ, Koukoulakis P, Asano T (2010) Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. Agricultural Water Management 97: 1233-1241
Prabu SL, Suriyaprakash T, Kumar JA (2011) Wastewater treatment technologies: a review. Pharma Times 43: 55-62
Qadir M, Sharma BR, Bruggeman A, Choukr-Allah R, Karajeh F (2007) Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agricultural water management 87: 2-22
Qureshi AS, Hussain MI, Ismail S, Khan QM (2016) Evaluating heavy metal accumulation and potential health risks in vegetables irrigated with treated wastewater. Chemosphere 163: 54-61
Rice J, Wutich A, White DD, Westerhoff P (2016) Comparing actual de facto wastewater reuse and its public acceptability: A three city case study. Sustainable Cities and Society 27: 467-474 DOI https://doi.org/10.1016/j.scs.2016.06.007
Rost S, Gerten D, Bondeau A, Lucht W, Rohwer J, Schaphoff S (2008) Agricultural green and blue water consumption and its influence on the global water system. Water Resources Research 44
Sadoff CW, Borgomeo E, Uhlenbrook S (2020) Rethinking water for SDG 6. Nature Sustainability 3: 346-347 DOI 10.1038/s41893-020-0530-9
Sánchez-Cerdà C, Salgot M, Folch M (2020) Reuse of reclaimed water: What is the direction of its evolution from a European perspective?Advances in Chemical Pollution, Environmental Management and Protection:1-64.
Scheierling SM, Bartone C, Mara DD, Drechsel P (2010) Improving wastewater use in agriculture: An emerging priority. World Bank Policy Research Working Paper
Schellenberg T, Subramanian V, Ganeshan G, Tompkins D, Pradeep R (2020a) Wastewater Discharge Standards in the Evolving Context of Urban Sustainability–The Case of India. Frontiers in Environmental Science 8 DOI 10.3389/fenvs.2020.00030
Schellenberg T, Subramanian V, Ganeshan G, Tompkins D, Pradeep R (2020b) Wastewater discharge standards in the evolving context of urban sustainability–The case of India. Frontiers in Environmental Science: 30
Setter T, Laureles E, Mazaredo A (1997) Lodging reduces yield of rice by self-shading and reductions in canopy photosynthesis. Field Crops Research 49: 95-106
SFD (2020). Shit Flow Diagram Kanpur, India; CSE India: New Delhi, India, 2020
Shahabadi MB, Yerushalmi L, Haghighat F (2009) Impact of process design on greenhouse gas (GHG) generation by wastewater treatment plants. Water research 43: 2679-2687
Sharma VP, Thaker H (2010) Fertiliser Subsidy in India: Who Are the Beneficiaries? Economic and Political Weekly 45: 68-76
Shende AD, Pophali GR (2022) Sewage and faecal sludge management; revisiting discharge standards in India. International Journal of Environmental Science and Technology DOI 10.1007/s13762-022-04688-6
Shoushtarian F, Negahban-Azar M (2020) Worldwide regulations and guidelines for agricultural water reuse: a critical review. Water 12: 971
Singh KP, Mohan D, Sinha S, Dalwani R (2004) Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area. Chemosphere 55: 227-255
Singh P (2006) Bridging the Ganga action plan: Monitoring failure at Kanpur. Economic and Political Weekly: 590-592

Singh RP (2001) Effect of wastewater disposal and extent of industrial pollution in and around Kanpur, Uttar Pradesh, India. Bulletin of Engineering Geology and the Environment 60: 31-35 DOI 10.1007/s100640000079
Skoet J, Stamoulis KG (2006) The state of food insecurity in the world 2006: Eradicating world hunger-taking stock ten years after the world food summit Food & Agriculture Org.
Smol M, Adam C, Preisner M (2020) Circular economy model framework in the European water and wastewater sector. Journal of Material Cycles and Waste Management 22: 682-697 DOI 10.1007/s10163-019-00960-z
Song G (2004) Cost benefit analysis of a wastewater treatement plant in Huai River Basin. Henan Province (In Chinese)
Sphere Association (2018) Sphere handbook: humanitarian charter and minimum standards in humanitarian response Practical Action
Srinivasan JT, Reddy VR (2009) Impact of irrigation water quality on human health: A case study in India. Ecological Economics 68: 2800-2807 DOI https://doi.org/10.1016/j.ecolecon.2009.04.019
Strauss M, Blumenthal UJ (1990) Human waste use in agriculture and aquaculture. Utilization, practices and health perspectives, executive summary International Reference Center for Waste Disposal Report 9: 90
Talebizadeh M, Belia E, Vanrolleghem PA (2014) Probability-based Design of Wastewater Treatment Plants.
Topare NS, Attar S, Manfe MM (2011) Sewage/wastewater treatment technologies: a review. Sci Revs Chem Commun 1: 18-24
Truchado P, Gil MI, López C, Garre A, López-Aragón RF, Böhme K, Allende A (2021) New standards at European Union level on water reuse for agricultural irrigation: Are the Spanish wastewater treatment plants ready to produce and distribute reclaimed water within the minimum quality requirements? International Journal of Food Microbiology 356: 109352 DOI https://doi.org/10.1016/j.ijfoodmicro.2021.109352
United Nations (2018) Urbanization. Our world in data
Van der Hoek W, Hassan MU, Ensink JH, Feenstra S, Raschid-Sally L, Munir S, Aslam R, Ali N, Hussain R, Matsuno Y (2002) Urban wastewater: a valuable resource for agriculture: a case study from Haroonabad, Pakistan IWMI
WHO (2006) WHO guidelines for the safe use of wasterwater excreta and greywater World Health Organization
WHO (2021) Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs.
Zarocostas J (2022) The UN reports global asymmetries in population growth. The Lancet 400: 148 DOI https://doi.org/10.1016/S0140-6736(22)01323-X