EVALUATION OF ARSENIC REMOVAL PLANTS BASED ON ADSORPTION AND ION EXCHANGE IN BUXAR, BIHAR

A DISSERTATION

Submitted in partial fulfilment of the

Requirements for the award of the degree of

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HYDROLOGY

By

RAJTOSH KUMAR JHA

DEPARTMENT OF HYDROLOGY

INDIAN INSTITUTE OF TECHNOLOGY

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DECLARATION

I hereby declare that the work carried out in this Dissertation titled EVALUATION OF ARSENIC REMOVAL PLANTS BASED ON ADSORPTION AND ION EXCHANGE IN BUXAR, BIHAR is presented on behalf of partial fulfillment of the requirement for the award of degree of Master of Technology in Hydrology, submitted to Department of Hydrology, Indian Institute of Technology, Roorkee, India, under the supervision of Professor Dr. Himanshu Joshi.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date: 26/06/2019

Place: Roorkee, India

Rajtosh Kumar Jha

(17537016)

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Dr. Himanshu Joshi

Professor

Department of Hydrology
Indian Institute of Technology

Roorkee, Uttrakhand

ABSTRACT

There are various schemes of treating water around the globe to suffice potable water needs. Arsenic contamination in potable water has a long history to follow. The death of Napoleon Bonaparte was contradicted as he was supposed to have died due to arsenic contamination. In modern world arsenic contamination in potable water has been measure affect to human health in arsenic prevalence zones. To mitigate the arsenic problem there has been many methods of arsenic removal from ground water source being researched and implemented. Installation and design of such systems are mostly based on affordability, target communities, technical performance and reliability. While evaluating an Arsenic removal system these factors are always compared for different technologies.

LCA is a robust tool to evaluate environmental impacts generated by a product system. In recent times, sustainability of a product or process is always considered with the environmental impacts associated with it. Thus, LCA can be a tool to provide environmental indicators in form of midpoint and endpoint impacts for evaluating an arsenic treatment technology too.

This study evaluates two arsenic removal plants in rural Bihar on the basis of technical and socio-economic factors and also finds the life cycle impact assessment of these processes. The results from both the methodology are compared against each other and identify the best among these. Two of the plants in Simri, block Buxar, Bihar were compared using Open LCA software for inventory analysis and Life cycle impact assessment.

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ABBREVIATION

AA- Activated Alumina

CGWB- Central Ground Water Board

CML- Centrum Voor Milieukunde

CPVC- Chlorinated Polyvinyl Chloride

FRP- Fiberglass reinforced plastic

GAC- Granulated Activated Carbon

HIAX- Hybrid Anion Exchange Resin

IIC- Institute Instrumentation Center

IIT- Indian Institute of Technology

INR. - Indian Rupees

IS- Indian Standards

ISO- International Standards Organization

LCA- Life Cycle Assessment

LCI- Life Cycle Inventory

LCIA- Life Cycle Impact Assessment

MCS- Mahaveer Cancer Sansthan

NGOs - Non-Governmental Organizations

NIH- National Institute of Hydrology

NTU- Nephelometric Turbidity Unit

PHED -Public Health and Engineering Department

PV- Photovoltaic

PVC- Polyvinyl Chloride

RO- Reverse Osmosis

TDS- Total Dissolved Solids

TOC- Total Organic Carbon

USEPA- United States Environment Protection Agency

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CHAPTER 1

INTRODUCTION

1.1 Background

While the selection of the best Arsenic removal system is based generally on economic and technical factors. But, the Arsenic removal plants may have environmental impacts, like depletion of natural resources and release of pollutants into the water, land and air through chemicals, consumables and energy consumption. With the recent developments in technology, there is increasing need for a common methodology to evaluate the reliability of alternative processes and treatment facilities that utilize different combinations of those processes.(Eisenberg et al. 2001)

Arsenic removal/treatment from groundwater has been experimented and researched from almost two decades now in India. There are various kinds of Arsenic Removal Plants Installed by different agencies through new researches but evaluation of the plants is merely done by these agencies. Comparative evaluation of Arsenic removal plants in Bihar have been posed due to various technical/socio-economic constraints and environmental impacts. The technical viability of the arsenic removal process based on reliability, simplicity and efficiency of the system is considered in terms of long and short-run. Socio-economic factors like favorable conditions for installation, area occupied, cost of the system, target community and acceptability are considered for comparison among different types of arsenic

Figure 1 : An arsenic removal plant in Nathnagar Block, Bhagalpur,Bihar

removal plants. Life cycle assessment based on life cycle inventories involved in the removal process during installation and operation with their life cycle impact assessment on the basis of continuity of facility provision/operation can be useful for comprehensive evaluation of these Arsenic removal technologies.

Arsenic Removal plants in Bhagalpur Bihar and Buxar, Bihar installed by Public Health and Engineering Department of Govt. of Bihar are commonly based on adsorption by activated alumina, Ion Exchange and coagulation-assisted microfiltration technology of similar capacities and costs. While some ion exchange based technologies are installed in places like Maner and Buxar in Bihar by some NGOs. A diverse distribution of community based arsenic removal plants with different technologies are installed within the arsenic prevalence regions in Bihar on banks of Ganga River. Thus, a comprehensive evaluation including Techno-Economic Tools and Life Cycle Assessment methods is to be done for these technologies in Indo-Gangetic region.

1.2 Objectives

- Understand the functional capability of different kinds of community based Arsenic Removal Plants/technologies.
- To collect physical data for understanding some conventional Arsenic removal system in study area
- Evaluate the base case environmental outcomes, technical reliability, simplicity, removal efficiency and costs to provide a baseline for comparison to alternative arsenic removal technologies through LCA.
- Establish an LCA, Technical framework that could be used to study other technologies or changes to arsenic removal systems and impose environmental criteria in decision making process.

CHAPTER 2

LITERATURE REVIEW

2.1 General

2.2 Arsenic Issues occurrence and Impacts

Arsenic is one of the most serious inorganic contaminants in drinking water on a worldwide scale. The maximum contamination level (MCL) is 10 µg/l for drinking water as per World Health Organization and IS 10200 2012, specifications. Arsenic is available in both organic and inorganic form in ground water. Both inorganic and organic compounds are typically white to colorless powders Arsenic in its pure form is insoluble in water while in oxidized form it is soluble in water.(Kartinen and Martin 1995). Some arsenite (III) and arsenate (V) forms are less stable and are interchangeable, depending on the chemical and biological conditions Some chemical forms of arsenic adhere strongly to clay and organic matter, which can affect their behavior in the environment. (NIH, CGWB 2010).

Table 1 : Chemical classification of Arsenic element

Symbol	*As*
Atomic Number	33
Atomic weight	74.92
Density	5.7 $g.cm^{-3}$ @ 14°C
Group	15 (VA)
Oxidation states	-3(Arsenides) +3(Arsenites) or As(III) +5(Arsenates) or As(V)

The toxicity of As varies greatly according to its oxidation state; for example As (III) is more toxic than As (V).(Gupta, Chen, and Gupta 1978). Arsenic in groundwater generally co-exist with Iron and manganese in ground water. The four samples analyzed for this study contained (258.5, 1446.8, 622.2, 185.0) ppb of iron and (79.5, 67.0, 20.5, 13.6) ppb of Manganese with (23.5, 188.05, 48.65, 6.08) ppb of Arsenic.

Table 2 : Arsenic leaching and oxidation states

$FeAsS + O_2 + H_2O >> AsO_4^{-3} + Fe^{+3} + SO_4^{-2} + H^+$	*Arsenic leaching from ore*
$H_3AsO_3 >> H^+ + H_2AsO_3^-$ (As III) $H_2AsO_3^- >> H^+ + HAsO_3^{-2}$	Oxidation State
$H_3AsO_4 >> H^+ + H_2AsO_4^-$ (As V) $H_2AsO_4^- >> H^+ + HAsO_4^{-2}$	Oxidation State

About 55 million people in Bihar are drinking water containing arsenic > 10 ppb. This has caused various health-related problems in the population like skin diseases, anemia, bronchitis, gastrointestinal problems, hormonal imbalance and cancer. Cancer risk is associated with daily consumption of 2 litres of water with inorganic arsenic 50 μg/L has been estimated to be 1/100 denotes that elevated blood arsenic levels in population can lead to cause various diseases including cancer.(Tchounwou et al. 2015) Long-term Arsenic exposure via drinking water can cause cancer of the skin, lungs, urinary bladder, and kidneys. With long term exposure the first changes are usually seen in the skin pigments (indicator of arsenic poisoning), then hyperkeratosis(Ghosh et al. 2007)

2.3 Arsenic Treatment technologies

There are many arsenic removal processes from drinking water and have been in research interest for 3-4 decades. There are many technologies including processes like oxidation/reduction, precipitation, sorption, solid/liquid separation, physical exclusion and biological removal. Conventional arsenic removal technologies can be used together with different removal medias in combination for example activated carbon and activated alumina are used together in arsenic removal plants. Membrane methods are followed by pre-oxidation for higher efficiencies.

Table 3 : Arsenic removal processes and efficiency adapted from (NIH Roorkee, 2010) (Singh, Singh, Parihar, Singh, & Prasad, 2015) (USEPA, 2010)

S.N.	*Methods*	*Types*	*Removal efficiency without modifications*	
			As (III)	As (V)
1	Oxidation and filtration	- Air Oxidation	≤ 30%	≤ 30%
		- Chemical Oxidation	≤ 30%	≤ 30-60%
2	Coagulation/Co-precipitation and filtration	- Alum Coagulation	≤ 30%	≥ 90%
		- Electrocoagulation	60-90%	≥ 90%
3	Sorption Methods	- Activated Alumina	60-90%	≥ 90%
		- Ion Exchange Resins	60-90%	≥ 90%
4	Membrane Methods	- Nano filtration	60-90%	60-90%
		- Reverse Osmosis	60-90%	60-90%
		- Electrodialysis	60-90%	≥ 90%

Some of the conventional technologies for arsenic removal in India are discussed below:

2.3.1 Oxidation and Filtration

Oxidation Changes the soluble As(III) to As(V) and then it is sedimentated as As(V). As(III) is predominantly present in ground water for which conversion is necessary as occurrence of is in soluble form. Oxidation is enhanced and removal efficiency is improved from below 30% to 70 % when Chemicals like chlorine (Cl_2), chlorine dioxide (ClO_2), ozone(O_3), Hydrogen peroxide (H_2O_2), Chloramine (NH_2Cl), Permanganate $(MnO_4)^-$, and ferrate $(FeO_4)^{-2}$. Following are some reactions involved:

$H_3AsO_3 + 1/2O_2 >> H_2AsO_4^- + 2H^+$ (air oxidation)

$H_3AsO_3 + HClO >> HAsO_4^{-2} + Cl^- + 3H^+$ (using Hypochlorous acid)

$3H_3AsO_3 + 2KMnO_4 >> 3AsO_4^{-2} + 2MnO_2^+ + 2K^+ + 4H^+ + H_2O$ (Using Potassium permanganate)

2.3.2 Coagulation and Filtration

A coagulant is added to contaminated water which results in formation of flocs (larger particles) these flocs are settled under influence of gravity and then filtered. Aluminum sulfate [$Al_2 (SO_4)_3 .18 H_2O$], ferric chloride $FeCl_3$, ferric sulfate [$Fe_2 (SO4)_3 .7 H_2O$] are some common coagulants used in arsenic treatment. Electrocoagulation or (ECAR) is a coagulation process alternative process to conventional CF (coagulation/flocculation). Instead of adding a chemical reagent as ferric chloride, metallic cations are directly generated in the effluent to be treated by applying a current between iron electrodes to dissolve soluble anodes.(Singh, et al., 2015). Electrocoagulation using various sacrificial metal anodes such as aluminum, iron, magnesium, etc. is found to be very effective for arsenic decontamination.(S. Amrose et al. 2013)

2.3.3 Adsorption

Adsorption by different media is used mostly due to high removal efficiency, easy operation/handling in point of use systems, low cost and minimum waste. Adsorption is a process that uses solids for removing substances from either gaseous or liquid solutions.(Singh et al. 2015) Several studies have been done for development of different materials based on Activated alumina, Activated Carbon, Iron oxides, Zeolites clays etc. 0.003 g to 0.112 g of Arsenic is absorbed by 1 g of Activated Alumina. Laboratory experiments indicate that arsenic removal can be accomplished in As(V) state (Gupta et al. 1978). For complete removal of As(III) pre-treatment may be required according to raw water quality.

2.3.4 Ion Exchange

Ion exchange is a physical/chemical process by which an ion on the solid resin phase is exchanged for an ion in the feed water. The solid resin is typically an elastic three-dimensional hydrocarbon network containing a large number of ionizable groups electrostatically bound to the resin**.**(Singh et al. 2015) They are used to replace the undesired ions with ion attached to the resins. Strong base anion exchange resins are used for arsenic removal. Hybrid anionic resin like HIAX (trade name) based on Hydrous Zirconium oxide is commonly used in India for arsenic removal at point of use treatments. Following is an example of ion exchange reaction for resin represented as R:

$$2R\text{-}Cl + HAsO_4^{-2} >> R2HAsO_4 + 2Cl^-$$

$R2HAsO_4 + 2H^+ + 2Cl^- >> 2R\text{-}Cl + HAsO_4^{-2} + 2H^+$

2.3.5 Membrane Technology

Membranes are typically synthetic materials with billions of pores or microscopic holes that act as a selective barrier; the structure of the membrane allows some constituents to pass through, while others are excluded or rejected.(Singh et al. 2015)

Table 4 : types of membrane technology

S. N.	*Membrane Technology*	*Pore size*	*Removal capacity*
1	Microfiltration	0.1 to 10 µm	Can remove suspended particles
2	Ultra Filtration	0.01 to 0.1 µm	Can remove suspended particles and dissolved substances if they are pre-absorbed or coagulated
3	Nano Filtration	0.001 to 0.01 µm	Can remove most organic impurities and a range of salts
4	Reverse Osmosis	0.0001 µm	Remove most minerals present in water and monovalent ions too.

Choice of the membrane technology can be based on the desired removal efficiency of Arsenic and raw water quality.

2.4 Technical, Socio-economic Evaluation and Life Cycle Assessment of Treatment technologies

There are few studies on evaluation and performance assessment of Arsenic removal technologies. However, there are few good publications like (USEPA 2010).This publication discusses the Arsenic Treatment Design Criteria by oxidation and filtration, adsorption media, membrane and ion exchange treatment methods. Further it provides guidelines for input water quality, removal efficiency for treatment using different methods and their limitations with capital costs in the place of origin.

Hossain et al., (2006) has discussed the evaluation of small systems of West Bengal with respect to performance of the Arsenic removal systems based on chemical parameters of the filtered water

Table 5: Issues with conventional arsenic removal systems

S.N.	***Conventional Arsenic Removal Technologies***	***Water loss***	***Waste generated***	***Treatment Issues***
1	Oxidation and filtration with chemicals	(1-2) %	Backwash water	Phosphate and silicate may reduce arsenic removal rates. Low removal rates for As(III)
2	Coagulation and Filtration	(1-2) %	Arsenic rich sludge	Low efficiency in removal of As (III)
3	Ion-Exchange Resins	(1-2) %	Backwash water and spent brine and media	Interference from sulfate and TDS. May require pre-treatment
4	Absorption	(1-2) %	Spent media and backwash water	Phosphate and Silicate may reduce arsenic removal rates. May require pre-oxidation
5	Membrane Methods	(40-60) %	Spent membranes and rejected high concentrated water	Issues on removal of arsenite, and low efficiency at high recovery rates, especially with low-pressure membranes.

(Boerschke and Stewart 2001) have assessed technologies based upon a rigorous performance criterion, followed by verification under conditions of actual use in Bangladesh.

An arsenic removal technology must be : (a) consistently effective to international and local arsenic standards in diverse and relevant groundwater compositions, (b) reliable and robust in the field with minimal and low-skilled maintenance, (c) low cost enough for clean water to be locally affordable with necessary business margins, (d) operable with minimal risk to safety and the environment, and (e) culturally acceptable to the local population.(S. E. Amrose et al. 2013). All the above points confirm an arsenic removal technology to be reliable and affordable on a community scale.

While all the relevant evaluation works mentioned above included methods of comparison of systems constituents, costs, methods, removal efficiencies of different raw water contaminants, social factors. None of these works accounted for environmental impacts generated by the system.

Some works on life cycle assessment of water treatment plants have been put through like (Vince et al. 2008). The assessment of energy and environmental impacts from the production of potable water for different processes involved in potable water production.(R. Gemma Raluy 2005) this work has compared two desalination processes i.e. thermal desalting with RO membrane separation and their environmental impacts.(Bonton et al. 2012) has performed LCA analysis for comparison of conventional GAC systems with Nano filtration water treatment systems with same quality of raw and treated water quality.Ecoinvent 2.2 database was used for reference with Simapro software.

(Loubet et al. 2014) have compared the life cycle assessment practices of different urban water systems. This work has classified works on LCA of different water technologies including 100+ works on unit process of water treatment and 24 plants and networks of technological urban water systems. This work suggested some guidelines for LCA of water systems for adaptation of LCA framework, forecasting scenarios, system boundaries, inventory compilations, mass balance of outputs flows, LCIA development, advances in LCIA and inclusion of uncertainty.

CHAPTER 3

STUDY AREA

3.1 General

Up to march 2019, 2, 36,637 drinking water samples from different sources tested in 13 arsenic affected districts of Bihar, 37,413 of water samples were having arsenic contamination more than specified standards i.e. > 10 ppb. Arsenic contamination was first detected in Bihar in 2002 in Simariya, Ojhapatti village in Bhagalpur district. Currently there are 276 Solar powered/electricity operated mini -water supply schemes with arsenic water treatment facility in 12 districts (PHED-Bihar, 2019)

Table 6: Arsenic affected regions in Bihar, (PHED-Bihar, 2019)

S.N.	*District Name*	*Total Blocks*	*Total Affected Blocks*	*Total Affected Habitation*
1	Begusarai	18	4	84
2	Bhagalpur	46	4	159
3	Bhojpur	14	4	31
4	Buxar	11	4	385
5	Darbhanga	18	1	5
6	Katihar	16	5	26
7	Khagaria	7	4	246
8	Lakhisarai	7	3	204
9	Munger	9	4	118
10	Patna	23	4	65
11	Samastipur	20	4	154
12	Saran	20	4	37
13	Vaishali	16	5	76
	Total	225	50	1590

The Buxar district is situated between 25° 18' to 25° 45' latitudes north & 84° 20' to 84° 40' longitude east. The district is included in the Survey of India topo sheet number 72 C. Its geographical area is 1624 Km^2 with a population of 17,07,643. Out of 11 blocks in Buxar 4 are identified as Arsenic affected blocks (Simri, Chakki, Buxar and Berhampur). The maximum level recorded was 1929 μg/L in Tilak rai ka Hata Simri. (Kumar et al. 2016). There are 5 operating plants in two blocks 2 in Simri Block and 3 in Berhampur Block installed by PHED-Bihar and one by Tagore Sen Gupta foundation, USA. There are other few non-functioning plants in these blocks too installed by IIT Bombay and PHED-Bihar and one plant is still under construction at Sarenja village Chausa block. Water Sampling was done for analysis of four plants in these two blocks named as Tilak rai ka Hata, HIAX resin based plant, Khairapatti Simri Activated Alumina based Plant, Dhanchapara and Sapahi Bramhapur Hydrous Zirconium Cartridge based plant. All the PHED-Bihar plants are powered through solar pumping system and has a capacity of 10000 lpd. While plant installed by Tagore Sen Gupta foundation in Tilak Rai Ka Hata the electricity is sourced from local grid. We will be comparing one Activated Alumina plant in Khairapatti, Simri Block with HIAX resin based technology installed in Tilak Rai Ka Hata, Simri. The list of plants visited are as in Appendix D.

CHAPTER 4
METHODOLOGY

4.1 Methodology

In the first phase of the study several arsenic treatment units installed in different regions in Bihar was visited to understand the functioning of the installations. Nathnagar Block in Bhagalpur, Maner in Patna, Mozimpur Plant in Ara (Bhojpur district) (mitigation plant with multi village supply scheme) were some of the visited sites in coordination with PHED-Bihar and Mahaveer Cancer Sansthan (MCS), Patna. In the second Phase I visited the plants in operation in two blocks of Buxar district i.e. Berhampur and Simri Blocks. Five operating plants were visited and water sampling was done in 4 plants for raw and treated water

Figure 2 : testing water sample at Tilak Rai Ka Hata, Simri, Buxar

Figure 3 : An abandoned water ATM in Tilak Rai Ka Hata, Simri, Buxar

qualities. While the plants installed by PHED were not maintained regularly; plant installed in Tilak Rai Ka Hata by Tagore Sen Gupta foundation was regularly maintained and monitored. In this work we are comparing one plant which was in good condition and recently maintained in Khairapatti, Simri with Tilak Rai Ka Hata Plant, Simri. The Khairapatti Plant is installed by PHED- Govt. of Bihar and Tilak Rai Ka Hata plant was installed by Tagore Sen Gupta Foundation, USA. The methodology for this comparison can be summarized in following steps:

4.2 Site Selection and questionnaire preparation

Selection of sites was based on operating condition of plants. As many installations has been abandoned due to lack of trust of community. For this study we have chosen two different technologies one based on adsorption by activated alumina and another based on ion exchange by HIAX-resin which were operating in good conditions. The Khairapatti plant was installed in year 2012 while the plant in Tilak Rai Ka Hata was installed in 2016. A proper list of questionnaire with reference to technical socio-economic terms was developed for the study as in appendix C. Availability of required data for treatment plants was a major reason for selection of these two plants based on methodology requirement of the study.

4.3 Site observations and data collection

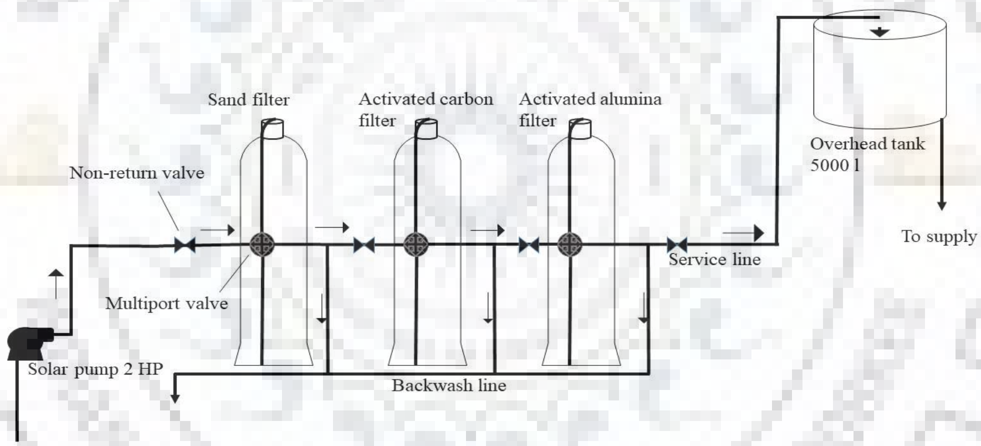

Figure 4 :Activated Alumina based plant in Khairapatti

The operating plants in Buxar district was visited and the data questionnaire was completed using interview of locals, plant operator, PHED representatives and personal experience. For collection of material flow data, site measurements were done The socio-economic and technical answers were reported as per actual at site. We collected some reference data as model estimates of construction and installation from PHED-Buxar office. While other related data was obtained on the basis of the questionnaire and site measurements. All the raw data were compiled and analyzed for further analysis. A set of primary data measures were extracted from the questionnaire. The observed flow scheme for Activated alumina based plant in Khairapatti Simri and HIAX resin based plant in Tilak Rai Ka Hata can be represented as in figures 4 and 5 Respectively.

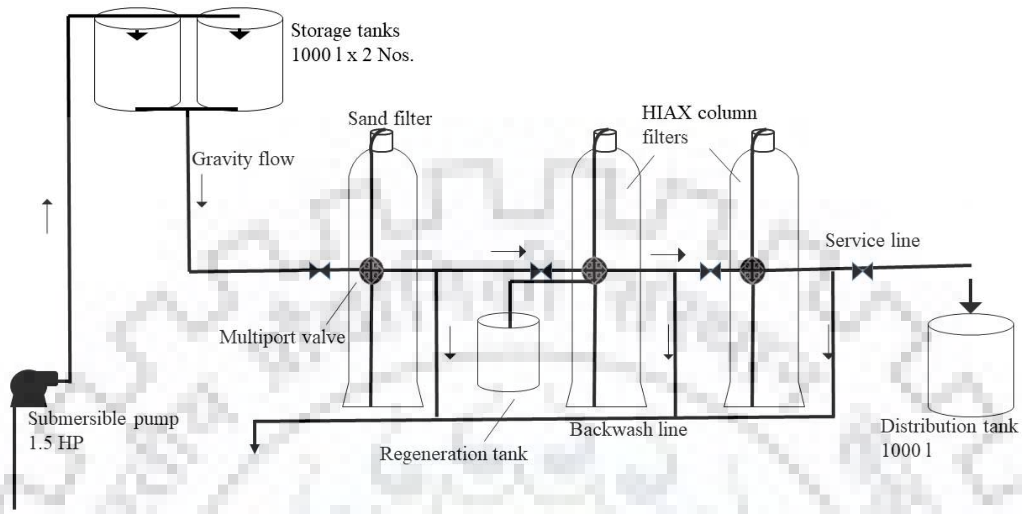

Figure 5: HIAX based plant in Tilak Rai Ka Hata

Some of the primary data was taken at site while others were generated from PHED-Buxar office for Khairapatti plant and Mahaveer Cancer Sansthan, Patna for Tilak Rai Ka Hata Plant. The table 7 shows the primary data obtained for both the plants.

Table 7: Primary data for arsenic treatment plants

SN	*Particulars*	*Unit*	*Khairapatti, Plant*	*Tilak Rai Ka, Hata plant*
1	Capacity	m^3/h	1.6666	0.8
2	Hours of Operation	h	6	6
3	No. of Households Served	Nos.	150	30
4	Capital cost	INR.	48,56,000	5,50,000
5	Power Consumption	KWh/d	8.952	3.357
6	Power Source		Solar Panels 1800 w	Local electricity Grid
7	Technology Used		Adsorption	Ion exchange
8	Media Used		Activated Alumina+ Activated Carbon	HIAX(Hydrous Zirconium oxide hybrid resin)
9	Media quantity	Kgs.	(100+100)	100
10	Sand	Kgs.	100	50
11	Gravels	Kgs.	100	50
12	Regeneration		Not required, media replacement suggested	Required, HCl, NaOH, NaCl

On socio-economic terms both the plants were serving same type of rural community. In Khairapatti plant the water was free but in Tilak rai Ka Hata the consumers were charged INR. 100 per month for every household. In Khairapatti plant, there was a proper distribution scheme for the entire community there were water distribution taps supplied by over-head tanks through gravity flow while in Tilak Rai Ka Hata, the households have to come to the plant to fill the water.

4.4 Water quality analysis

Water quality for raw and treated water was analyzed for both the plants for all the parameters recommended by (USEPA, 2010). The quality analysis for raw and treated water was tested at site, EHL lab DoH IITR and IIC IITR. The water sampling for water quality analysis was according as requirement of analysis parameters. The list of parameters for water quality tested and sampling method for the water sample are mentioned in Appendix-E

Figure 6: arsenic field test kit

Figure 7: turbidity meter

As the removal of arsenic is affected by water quality parameters like Turbidity, TDS, Sulfate, Silica, TOC etc. It was required to test all these parameters with other drinking water quality parameters. The parameters like temperature, color, pH, turbidity were performed at the plants as these parameters may deviate from actual due to time, temperature, light etc. Arsenic Strip test using Arsenic field test kit was also done at the plants.

4.5 Technical and Socio-economic analysis

The success of a community based installation is always dependent on the socio-economic status of the community. The rural community of Simri block, Buxar are major consumers of the water treated by these plants in Khairapatti and Tilak Rai Ka Hata. The technical and socio-economic analysis was done for comparison of both the arsenic removal plants through available data from questionnaire and water quality analysis. The analysis was based on the reliability, simplicity and removal efficiency in terms of technical factors and land requirement, affordability and social acceptability in terms of socio-economic factors.The technical elements like design considerations,technology used, arsenic removal capacity, operation and maintenance requirements, skill level for operation and maintenance, process of removal, system complexity, method of disposal of waste from plants, water quality parameters other than arsenic while the socio-economic elements like water distribution scheme, land acquirement, associated cost were considered for comparison. Special considerations for economic status of community, literacy and arsenic affected population will be included in reference to other studies in that area.

4.6 LCA analysis

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource

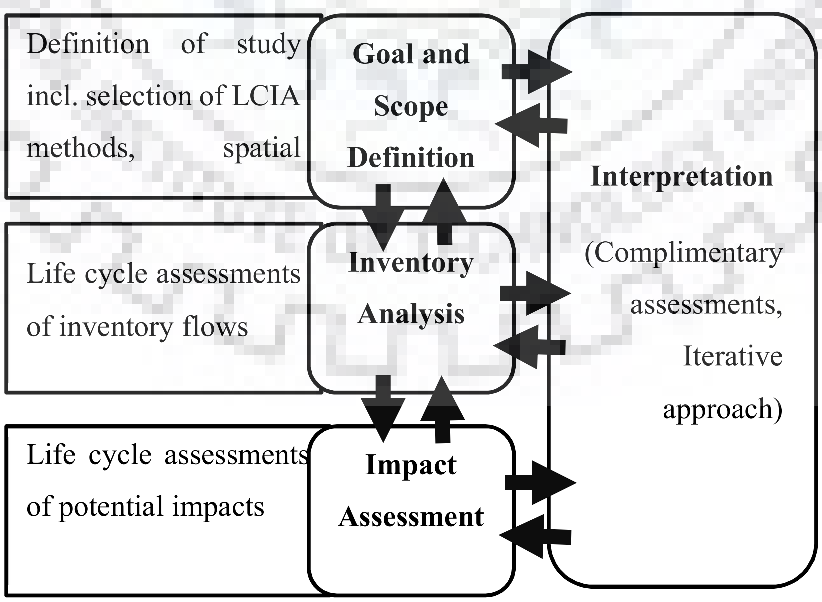

Figure 8 : LCA Frame work (ISO: 14040)

use, human health, and ecological consequences.(ISO, 2006). LCA has been applied to water technology assessment since the late 1990s (Loubet et al. 2014).

LCA was done for assessing the sustainability of the plants in respect to the environmental impacts of the different processes involved in installation, operation and demolition of the installations. Assessing potential environmental impacts helps to aggregate the effects on a basis that ensures a degree of comparability across locations(P fister et al., 2017). There are four different phases in a life cycle assessment (a) Goal and scope definition (b) Life cycle inventory (c) Life cycle impact assessment (d) Interpretation

4.6.1 Goal and Scope definition:

Goal definition and scoping is the phase of the LCA process that defines the purpose and method of including life cycle environmental impacts into the decision-making process(Curran 2006). The major goal of this study is to calculate the major environmental impacts generated by both the arsenic removal plants using two different technologies i.e. adsorption by activated alumina/ activated carbon and ion exchange by HIAX resin

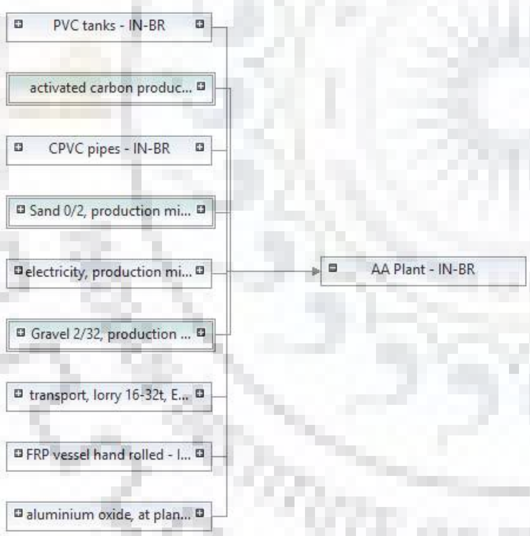

Figure 9 : Model flow of Activated alumina plant in Khairapatti product system

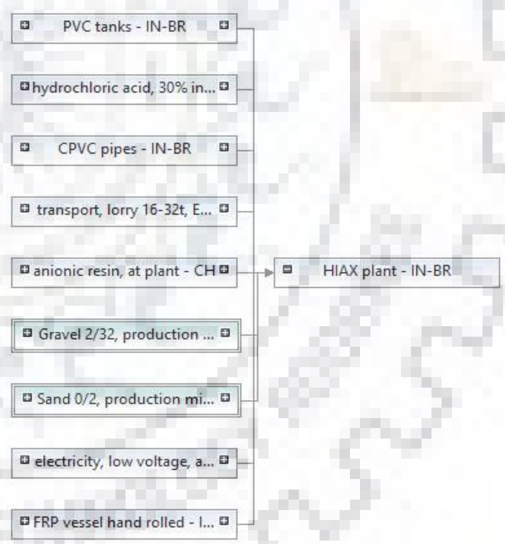

Figure 10 : Model flow of HIAX resin plant in Tilak rai Ka Hata product system

The functional unit of 1 m^3 of treated water is considered. The plants are considered operating for 6 hours daily for 20 years of life. The boundary of the system is considered from inlet of the pump to the outlet for distribution of water. The LCIA will be done through ReCiPe 2016 Midpoint (I) method and the software used is OpenLCA 1.8. The databases we are using is eco-invent 3.5 and elcd 3.2 by Greendelta. Both of these databases are freely sourced from OpenLCA nexus and OpenLCA 1.8 is also a free available software. The defined goal and scope will guide the entire process to ensure that the most meaningful results are obtained(Curran 2006). The life cycle phases like construction excluding building materials for infrastructure, operation (consumables and chemicals) and demolition of the system was considered for analysis of both systems. The raw and treated water quality of both the plants are considered same for LCA analysis.Figure 9 & 10 shows the model flow for both the treatment processes as per the product system for production of treated water. The various material and resources are transported to the location of production of treated water from production of materials required.

4.6.2 Life cycle inventory

Life Cycle Inventory analysis (LCI) is defined as a phase of Life Cycle Assessment (LCA) involving the compilation and quantification of inputs and outputs for a given product

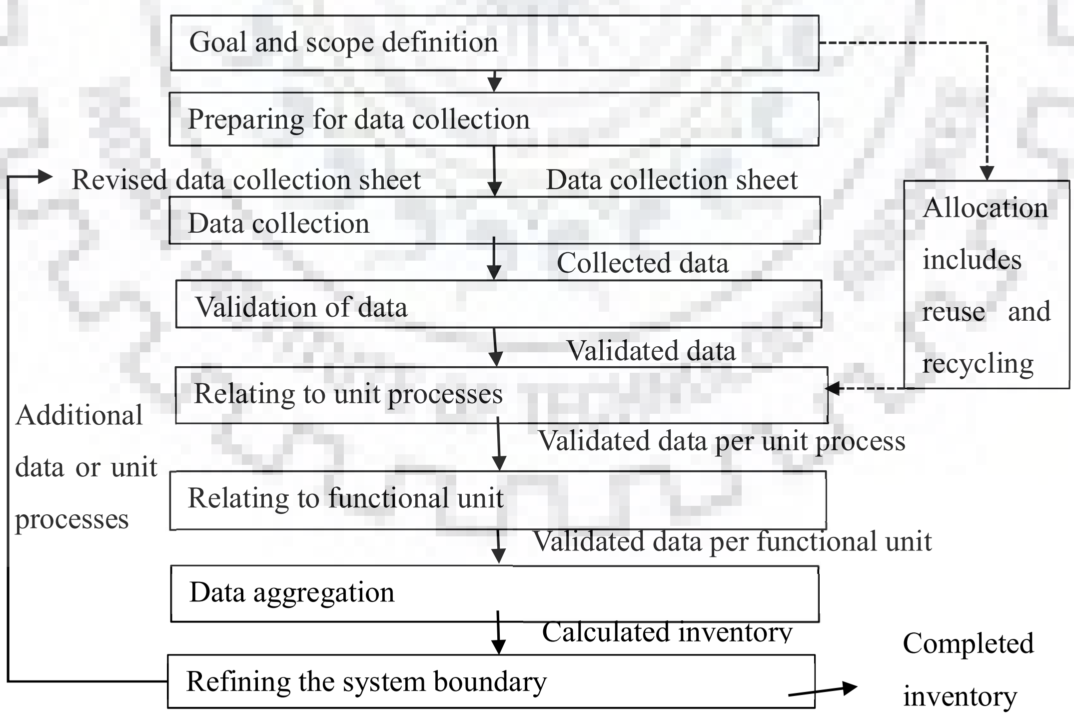

Figure 11: LCI framework for processes (ISO: 14042)

system throughout its life cycle (ISO 14040, 2006). Second phase of LCA includes preparation of inventories for all the inputs and output of unit processes used in the plants. The inventory preparation as suggested by ISO can be represented in figure 11. A group of

Table 8: Inventory list for Khairapatti plant

S.N.	*Component (Khairapatti)*	*Units*	*Value*
1	FRP vessels hand rolled	kg/m^3	2.68E-03
2	Activated Alumina	kg/m^3	1.37E-02
3	CPVC pipes	kg/m^3	7.84E-04
4	PVC Tanks	kg/m^3	2.74E-03
6	Sand	kg/m^3	1.37E-02
7	Gravel	kg/m^3	1.37E-02
8	Activated carbon granular	kg/m^3	1.37E-02
9	Electricity Photovolatic Mix	KWh/m^3	8.95E-01
10	Transportation Total	kg*km	9.00E+01
11	Pumps	Unit/ m^3	NC
12	Gate Valves	Unit/ m^3	NC
13	Multiport Valves	Unit/ m^3	NC
14	Totalizing flow meter	Unit/ m^3	NC
15	Waste water	m^3/m^3	1.33E-02
16	Plastic waste	kg/m^3	6.21E-03
17	Spent Activated alumina	kg/m^3	1.37E-02
18	Spent Activated Carbon	kg/m^3	1.37E-02
19	Spent Sand and Gravel media	kg/m^3	NC

inventories required for The inventory for Tilak rai Ka Hata plant and Khairapatti plants are as per in table 8 and 9. The inventory calculations are based on site measurements and reference standards/specification of materials. None of the co-product allocation methods were considered as the waste from plants are neither recycled nor reused as resources. The Khairapatti plant was powered by solar panels to operate DC pump of 2 HP. While Plant in Tilak rai Ka Hata was connected to local grid and the rated pump capacity was 1.5 HP.

The operation schema makes the electricity consumption less in Tilak Rai Ka Hata plant as the Pump is not in line with the plant and pressure generated in treatment vessels are due to gravity flow of raw water from above 4 m from ground.

Table 9 : Inventory list for Tilak Rai Ka Hata Plant

S.N.	*Component (Tilak Rai Ka Hata)*	*Units*	*Value*
1	FRP Vessels hand rolled	kg/m^3	1.66E-03
2	Arsenic Removal Media	kg/m^3	8.56E-03
3	CPVC pipes	kg/m^3	6.30E-04
4	PVC Tanks	kg/m^3	5.31E-03
5	Sand	kg/m^3	2.14E-02
6	Gravels	kg/m^3	2.14E-02
7	HCl	kg/m^3	1.13E-03
9	Electricity Mix grid	KWh/m^3	6.98E-01
10	Transportation Total	kg*km	8.38E+01
11	Pumps	Unit/ m^3	NC
12	Gate Valves	Unit/ m^3	NC
13	Multiport Valves	Unit/ m^3	NC
14	Totalizing flow meter	Unit/ m^3	NC
15	Plastic Waste	kg/m^3	7.60E-03
16	Waste water	m^3/m^3	8.68E-03
17	Spent Media	kg/m^3	8.56E-03
18	Spent Sand and gravel media	kg/m^3	NC

The vessel sizes used in Khairapatti are 16-inch dia. and 65-inch height whereas, 12-inch dia. And 48-inch height vessels are used in Tilak Rai Ka Hata plant. For both the plants the same supply chain was considered for similar materials used and the transportation distance was same for common materials. All the input value of material flow was normalized according to the functional unit of 1 m^3 of treated water flowing out of the product system. These inventories include the energy, chemicals, materials consumption and emissions associated with the plant. Some of the inventory inputs are not considered for both the plants due to insignificance or the very low value per unit of functional unit (< 1%) in the product system.

Table 10 : Ecoinvent Data quality assessment score

Data quality	***Reliability***	***Completeness***	***Temporal correlation***	***Geographical correlation***	***Further technological correlation***
Relevance	Verified data based on measurements	Representative data from only one site	Less than 10 years of difference to the time period of data	Data from area with similar production conditions	Data on related processes or materials
Score	**1**	**4**	**3**	**3**	**4**
Average Score	**3**	Best	**1**	Worst	**5**

The data quality system used in LCI is ecoinvent data quality schema as represented in table 10. The average Score of relevance to databases used for upstream processes is 3; this is because there are limitations used in databases used for the study.

4.6.3 Life cycle impact assessment

life cycle impact assessment is the phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system(ISO 14040, 2006). The impact assessment for the product system of AA plant and HIAX plant will be based on elementary input and output flows as resources consumption and emissions to the environment.

We are using ReCiPe 2016 Midpoint (I) as impact assessment method with no coproduct allocation. It contains 18 midpoint indicators and 3 endpoint impacts. The model for impact categories identified by ReCiPe is represented in figure 12. This method for LCIA was developed by National Institute for public health and the environment ministry of health welfare and sports Netherland. It had its last update in 2017 which makes it most recent impact assessment method.

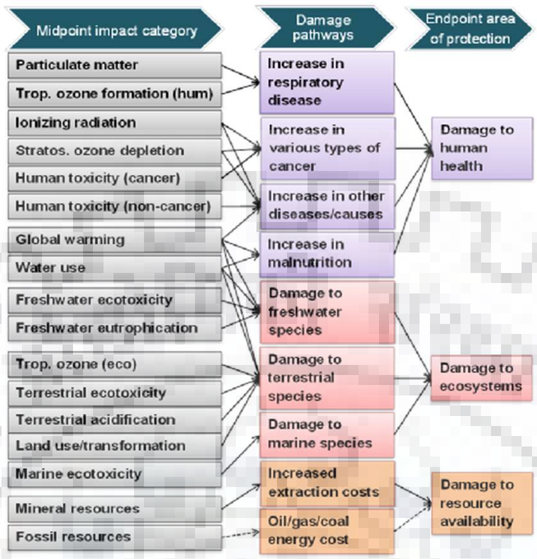

Figure 12: ReCepie Midpoint Impact Category (source:www.lcia-recipie.net)

Calculation of impact score for Impact Categories

Impact Score

$$\mathbf{I_s = \Sigma_x \Sigma_i \; CF_{i,x} * M_{i,x}}$$

$CF_{x,i}$ is the characterization factor of the substance i released to the compartment x (CTUe/kg); $M_{x,i}$ is the emitted mass of substance i to the compartment x (kg/d).

Characterization factor

CF = FF * XF * EF

Where (for freshwater Eco toxicity):

FF is the fate factor of the substance considered, expressed in days (d);

XF, its exposure factor (dimensionless);

EF, the effect factor expressed in PDF $m^3.kg^{-1}$

The main objective of the ReCiPe method is to provide a method that combines Eco-Indicator 99 and CML impact assessment methods, in an updated version.

CHAPTER 5

RESULTS

5.1 Results Technical and Socio-economic analysis:

Both the plant data were analyzed to extent. As there is interference of some specific water quality to both adsorption and ion exchange plants the list of parameters is as per table 11 and 12. In Khairapatti plant all the optimal raw water quality were below the limits except silica and iron which are 3.905 mg/l, 1.446 greater than the optimal values for adsorption media plant. Iron was 3 times greater than optimal value. It can affect the removal efficiency of arsenic

Table 11: Optimal raw water quality for adsorption plants (USEPA, 2010).

S.N.	*Parameters*	*Units*	*Optimal raw water quality for adsorption media plant USEPA*	*Raw water quality Khairapatti*
1	pH	-	6.0 – 9.0	7.3
2	Chloride	mg/l	< 250	4.23
3	Flouride	mg/l	< 2	0
4	Sulphate	mg/l	< 360	2.67
5	Silica	mg/l	< 30	33.905
6	Iron	mg/l	< 0.5	1.446
7	Mangnese	mg/l	< 0.05	0.066
8	TDS	mg/l	< 1000	460.48
9	TOC	mg/l	< 4	0

Table 12: Optimal raw water quality for ion exchange plants,(USEPA, 2010)

S.N.	*Parameters*	*Units*	*Optimal raw water quality for ion exchange plant USEPA*	*Raw water quality Tilak rai Ka Hata*
1	pH	-	6.5-9	7.37
2	Nitrate	mg/l	< 5	1.63
3	Sulphate	mg/l	< 50	37.331
4	TDS	mg/l	< 500	707.2
5	Turbidity	NTU	< 0.3	0

Where ion exchange plant in Tilak rai Ka Hata, TDS was major issue as it was nearly 1.5 times greater than the desired value While the arsenic removal was below the required standards in HIAX media plant, activated alumina plant the arsenic concentrations were 56.19 ppb which was almost 5.5 times above standards of 10 ppb.

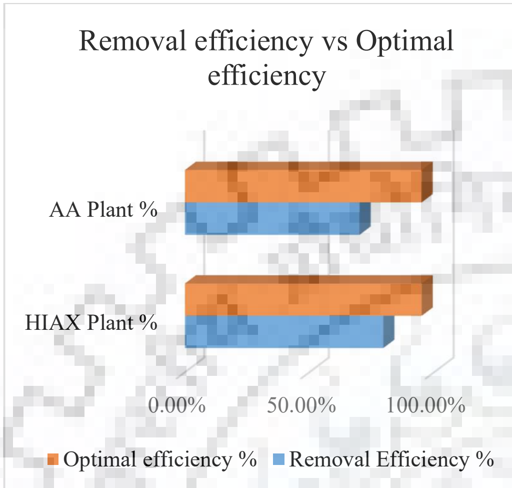

Figure 13 : Removal vs optimal efficiency

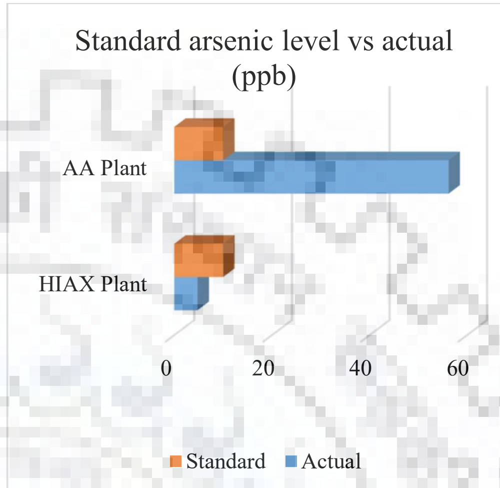

Figure 14: standard vs actual arsenic in treated water

While comparing the plants on the base of arsenic removal the HIAX media based plant had removal of 80% and activated alumina based plant's efficiency was only 70% against the optimal efficiency of the system to be 95%. The removal of other quality parameters was better in Khairapatti plant than in Tilak Rai Ka Hata plant. The detailed water quality and parameters removal are in annex.

Apart from water quality standards there are various technical and socio-economic factors associated with these plants. These factors are compared for both the plants in Khairapatti and Tilak Rai Ka Hata. The sense of ownership for the community plant in Tilak rai Ka Hata was observed more than that in the Khairapatti, plant. This may be because the no. of household served are less in Tilak rai Ka Hata than in Khairapatti. Though the Khairapatti plant is installed for drinking and cooking water purposes only but due to lack of awareness, the consumers are using it for other activities like washing, bathing etc. which makes the plant run on full capacity every time. This factor doesn't apply in Tilak Rai Ka Hata because there is no distribution

Table 13: Technical and Socioeconomic factors comparison for Khairapatti and Tilak Rai Ka Hata Plants

SN	*Factors*	*Khairapatti plant*	*Tilak Rai Ka Hata*
1	Design of system	Single service line with one button push start	As the plant is gravity flow the overhead tanks to be monitored time to time as required.
3	Capital cost	High capital cost. Infrastructure costs are more than plant costs	Minimum infrastructure cost as the plant is setup in an open shed.
4	Removal efficiency	Optimal: 90% Actual: 70%	Optimal: 95% Actual: 80%
5	Maintenance, backwash and regeneration	O&M is done by 3rd party allotted by PHED-Bihar. Backwash required every 24 h of operation regeneration not required as media replacement is suggested	plant operator from the community is in charge of maintenance backwash frequency is 24 h. regeneration required for every 16000 bed volumes.
6	Skill level for operation	Minimal	Minimal
7	Waste disposal	Backwash water, Used media. Backwash water used for kitchen gardening. Used media disposed in premises of plant several times	Backwash water, spent brine directly falls in waste sump. proper method for disposal of used media required
8	Distribution scheme	Distribution through pipeline by overhead gravity flow tanks to 15 distribution plants in village	No distribution lines. Water containers are filled at plant and carried to homes
9	Land area occupied	85 ft. X 65 ft.	20 ft. X 15 ft.
10	Electricity source	Solar PV pumping system	Connected to local grid
11	Satisfaction level	High	High
12	Revenue generated by the plant (INR.)	0	3000/month

scheme for treated water supply. While the electricity source is solar the Khairapatti plant can operate during sunshine hours only but there is no electricity cost for operation of this plant. While plant in Tilak rai Ka Hata being connect to local electricity grid it can be operated at any time. But the unpredicted load shedding in Bihar can affect their operation.

5.2 Results LCA Analysis

For both the system inputs there are more than 1900 processes involved in the upstream and downstream processes of the plants. The midpoints impact (I) with ReCiPe 2016 was compared against each other for both the plants within the system boundary obtained from LCIA analysis.

Table 14: LCIA Results

S.N.	*Impact category*	*Reference unit*	*Khaira Patti Plant*	*Tilak Rai ka Hata Plant*
1	Fine particulate matter formation	kg PM2.5 eq	3.18E-03	5.77E-03
2	Fossil resource scarcity	kg oil eq	4.44E-02	0.79E-01
3	Freshwater Eco toxicity	kg 1,4-DCB	7.12E-03	1.59E-02
4	Freshwater eutrophication	kg P eq	7.96E-05	3.42E-04
5	Global warming	kg CO_2 eq	2.07E+00	3.65E+00
6	Human carcinogenic toxicity	kg 1,4-DCB	1.67E+00	2.59E+00
7	Human non-carcinogenic toxicity	kg 1,4-DCB	5.85E+01	1.44E+02
8	Ionizing radiation	kBq Co-60 eq	4.48E-01	8.84E-01
9	Land use	m^2 a crop eq	1.29E-03	5.94E-03
10	Marine Eco toxicity	kg 1,4-DCB	7.57E+01	1.77E+02
11	Marine eutrophication	kg N eq	4.45E-05	8.35E-05
12	Mineral resource scarcity	kg Cu eq	4.88E-03	4.89E-03
13	Ozone formation, Human health	kg NO_x eq	4.85E-03	8.26E-03
14	Ozone formation, Terrestrial ecosystems	kg NO_x eq	4.89E-03	8.31E-03
15	Stratospheric ozone depletion	kg CFC11 eq	8.20E-07	3.05E-06
16	Terrestrial acidification	kg SO_2 eq	1.07E-02	1.95E-02
17	Terrestrial Eco toxicity	kg 1,4-DCB	2.76E+00	2.84E+00
18	Water consumption	m^3	2.06E+00	3.41E+00

The impacts generated by both the system in 18 midpoint categories are as in table 14. The product system of both the plants calculated with reference to basic inventory inputs. Table

15 shows the allocation methods, products and processes involved and the elementary flows of these systems

Table 15: No. of processes, products and flows in LCA analysis

Product system:	*Tilak Rai Ka Hata HIAX plant*
No. of processes:	1938
No. of products:	2023
No. of elementary flows:	2319
Product system:	Khairapatti Activated Alumina Plant
No. of processes:	1939
No. of products:	2024
No. of elementary flows:	2803
Allocation method:	None
Software:	OpenLCA
Version:	1.8.0
Database:	Ecoinvent 3.5

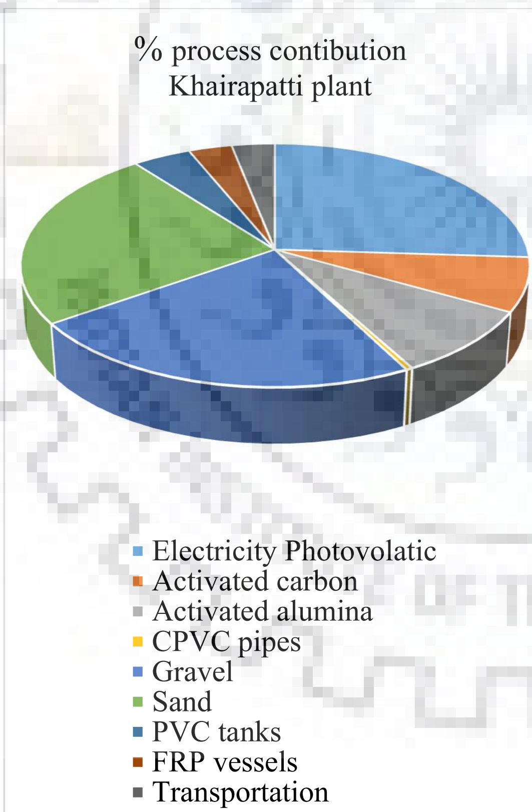

Figure 15: percent process contribution Khairapatti plant

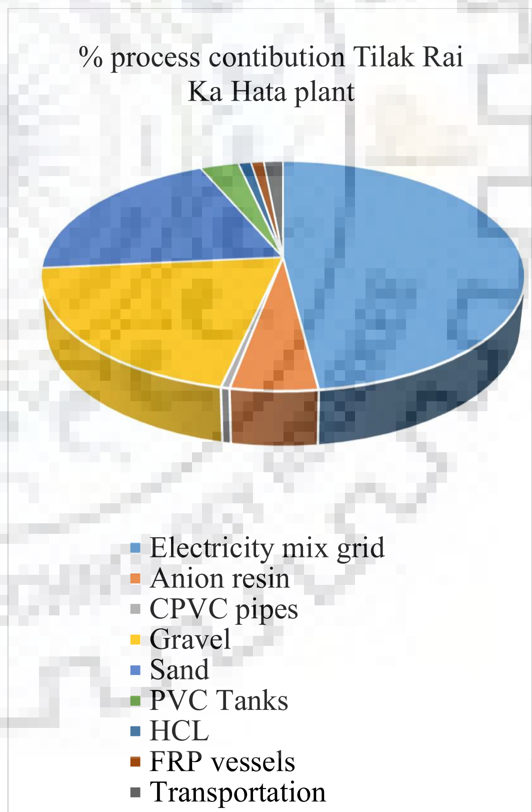

Figure 16: percent process contributions Tilak Rai Ka Hata

While the Khairapatti plant was powered by solar-PV pumping system and Tilak rai Ka Hata Plant was using electricity from local electricity grid. The percentage contribution of electricity generation and distribution in Tilak rai Ka Hata plant was 48% of total impacts generated by the system while it was 26% in Khairapatti plant. In both the plants electricity was the measure process contributor for impact categories in most of the categories was electricity. Thus, sustainable system should have an alternate source of energy for minimum impact as in Khairapatti. While the percentage impacts of pre-filter media (Sand and Gravels) in both the plants were nearly same around 40% in both the plants making it second

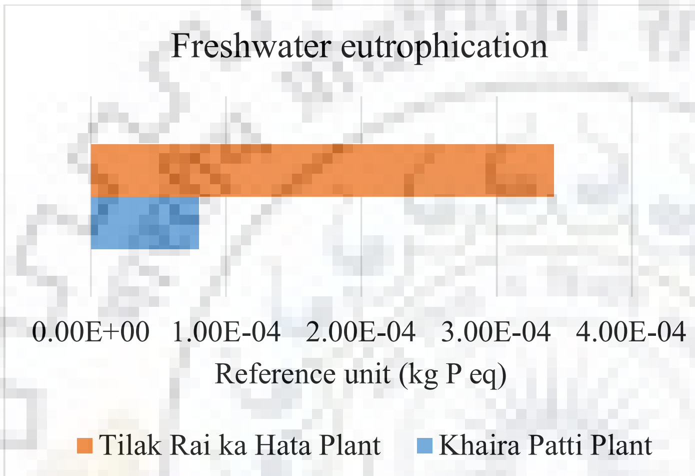

Figure 17 : freshwater eutrophication

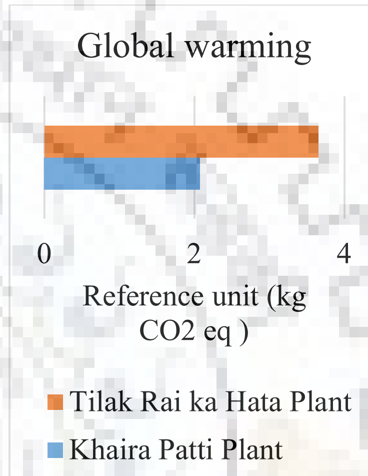

Figure 18: global warming

highest contributors in both the plants. The percentage contribution for associated processes to impact categories can be represented as in figure 15 and 16 contributions of input The

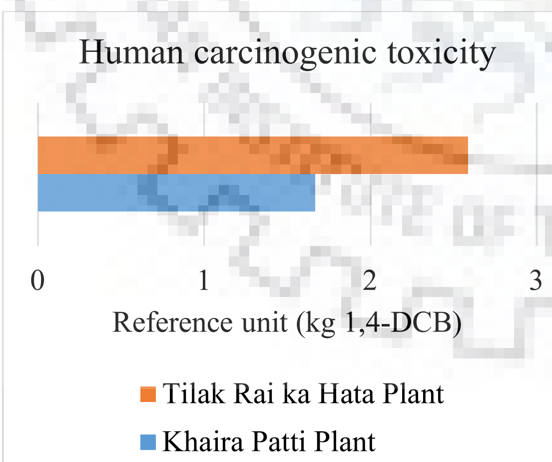

Figure 19 : human Carcinogenic toxicity

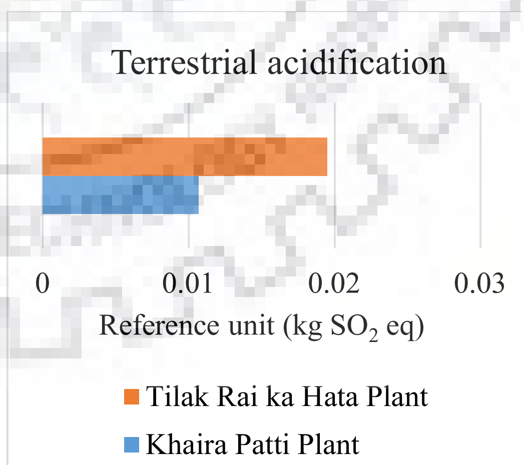

Figure 20: Terrestrial acidification

impacts category associated with the input processes are as in appendix G. Some of the impact categories for the both plants are compared against each other in figure 17 to 24.

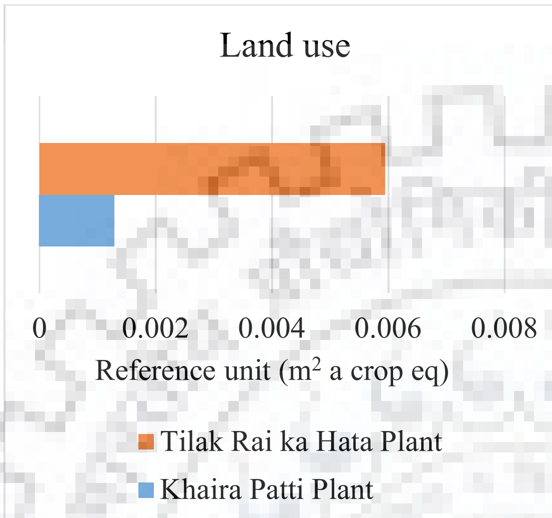

Figure 21: Land Use

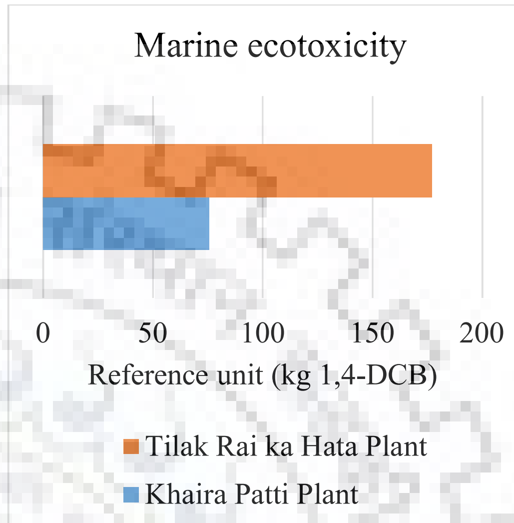

Figure 22: Marine Eco toxicity

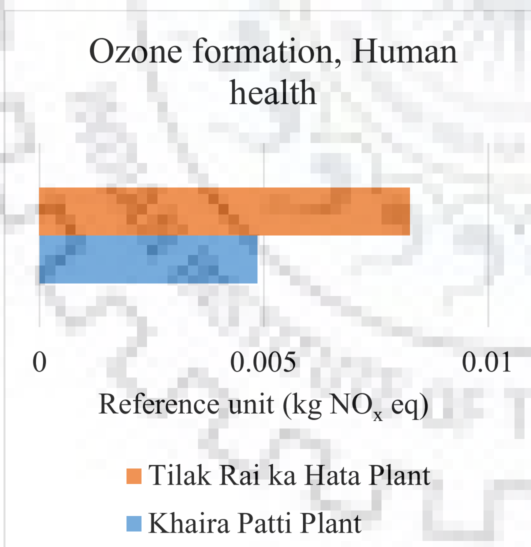

Figure 23: Ozone formation

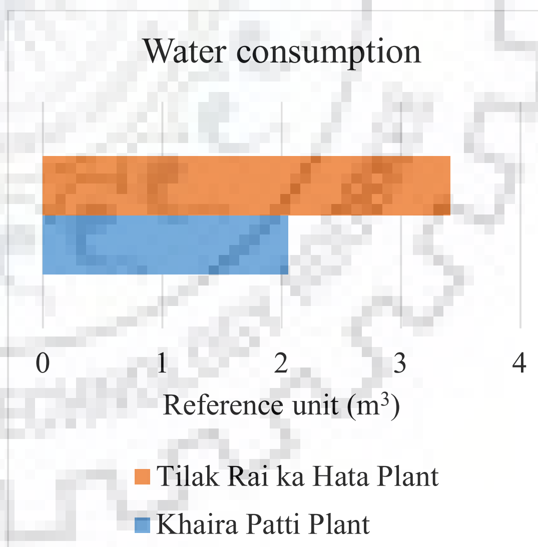

Figure 24 : Water consumption

CHAPTER 6
CONCLUSIONS

6.1 Conclusions

The comparison of both plants based on technical and socio-economic factors concludes that the plant in Tilak rai Ka Hata is more reliable on factors like operation and maintenance, affordability and self-sustainability.

While the targeted community for both the plants are of similar social and economic status, paying for water is still not well practice in this area. In these terms plant in Khairapatti provides free water with a well-designed distribution scheme. The level of arsenic in treated water in Khairapatti is high above standards but can be achieved to standards if proper maintenance practice is there. while the plant in Tilak rai Ka Hata is totally dependent on the revenue generated by its user but the Khairapatti plant is not. Both these plants are able to treat more than the water demand for the community targeted. The waste disposal procedures can be improved as the current practice is not as per standards in both plants.

While Technical and Socio-economic factors show that HIAX resin based plant in Tilak Rai Ka Hata performing better than the Plant based on adsorption by Activated Alumina in Khairapatti in present conditions. The LCIA interpreted results are better for Khairapatti plant in comparison to The Tilak Rai Ka Hata plant. The impacts generated per unit functional unit of 1 m^3 of treated water is very much higher in Tilak Rai Ka Hata plant. In both cases, the energy used for operation of these plants were major contributors in most of the impact categories. Whatever the media or processes are used, energy sourced for operation creates major difference in environmental impacts. The impact results for categories like freshwater Eco toxicity, freshwater eutrophication, ionizing radiation, human non-carcinogenic toxicity, marine Eco toxicity, ozone formation and fossil resource scarcity in Tilak rai Ka Hata plant are more than double that of Khairapatti plant. In all of 18 assessed impacts categories the Khairapatti plant have better environmental performance. Hence, on basis of environmental impact consideration, Khairapatti plant is way more sustainable than the Tilak Rai Ka Hata plant. Though technical and socio-economic factors are always major consideration for decision support system. The environmental results can be a major factor to consider while planning and designing these types of arsenic removal plants.

6.2 Limitations

While we conclude this work there are few limitations of this study really important to mention. The limitations can be listed as follows:

The data generated was based on personal interviews of operators, PHED representatives and only few users. A single set of questionnaire was only completed for one plant.

Not all the upstream processes involved in the model flow were accounted as more than 1900 processes, 2000 products and 2300 elementary flows were involved in the product systems of both the plants

The databases used for LCA analysis were developed in European manufacturing conditions which may not be same for manufacturing in Indian conditions

Two plants compared have different no. of operating hours as the Khairapatti plant was installed back in 2012 and Tilak Rai Ka Hata plant was installed in 2016.

The cost estimates of system may vary with those at present times as the model estimates are older. The raw water quality can also vary with time and initial design conditions

The water samples were analyzed once and no benchmarking was done to the water reports previously generated.

All the primary processes in the product system for both the plants were not present in the LCA databases; this may limit the outcomes of potent LCA analysis of arsenic removal plants.

The water quality parameters for As(III) and As(V) could not be analyzed for the efficiency comparison in dissolved and suspended stages of Arsenic.

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Appendix A

National drinking water quality standards IS 10200 2012

S. N.	parameters	Units	Requirement	Permissible limit	Method of test as per IS 3025
1	Colour	Hazen units	5	15	part 4
2	Odour		Agreeable	Agreeable	part 5
3	pH value		6.5-8.5	No relaxation	Part 11
4	Taste		Agreeable	Agreeable	Parts 7 and 8
5	Turbudity	NTU	1	5	part 10
6	Total dissolved solids	mg/l	500	2000	Part 16
7	Aluminium	mg/l	0.03	0.2	IS 3025 (part 55)
8	Ammonia	mg/l	0.5	No relaxation	IS 3025 (part 34)
9	Anionic Detergents	mg/l	0.2	1	Annex K of IS 13428
10	Barium	mg/l	0.7	No relaxation	Annex F of IS 13428*
11	Boron	mg/l	0.5	1	S 3025 (Part 57)
12	Calcium	mg/l	75	200	IS 3025 (Part 40)
13	Chloramines	mg/l	4	No relaxation	IS 3025 (Part 26)*
14	Chloride	mg/l	250	1 000	IS 3025 (Part 32)
15	Copper	mg/l	0.05	1.5	IS 3025 (Part 42)
16	Fluoride	mg/l	1	1.5	IS 3025 (Part 60)
17	chlorine	mg/l	0.2	1	IS 3025 (Part 26)
18	Iron	mg/l	0.3	No relaxation	IS 3025 (Part 53)
19	Magnesium	mg/l	30	100	IS 3025 (Part 46)
20	Manganese	mg/l	0.1	0.3	IS 3025 (Part 59)
21	Mineral oil	mg/l	0.5	No relaxation	Clause 6 of IS 3025
22	Nitrate	mg/l	45	No relaxation	IS 3025 (Part 34)
23	Phenolic compounds	mg/l	0.001	0.002	IS 3025 (Part 43)
24	Selenium	mg/l	0.01	No relaxation	IS 3025 (Part 56)
25	Silver	mg/l	0.1	No relaxation	Annex J of IS 13428
26	Sulphate	mg/l	200	400	IS 3025 (Part 24)
27	Sulphide	mg/l	0.05	No relaxation	IS 3025 (Part 29)
28	Total alkalinity	mg/l	200	600	IS 3025 (Part 23)
29	Total hardness	mg/l	200	600	IS 3025 (Part 21)
30	Zinc	mg/l	5	15	IS 3025 (Part 49)
31	Cadmium	mg/l	0.003	No relaxation	IS 3025 (Part 41)
32	Cyanide	mg/l	0.05	No relaxation	3025 (Part 27)
33	Lead	mg/l	0.01	No relaxation	IS 3025 (Part 47)
34	Mercury	mg/l	0.001	No relaxation	IS 3025 (Part 48)
35	Molybdenum	mg/l	0.07	No relaxation	IS 3025 (Part 2)
36	Nickel	mg/l	0.02	No relaxation	IS 3025 (Part 54)

Appendix B

Water quality analysis methods

S. N.	Parameters	Equipment used	Sampling method	Remarks
1	Conductivity	Conductivity meter	Pre calibrated probe, meter, 5 times diluted sample	Field test
2	pH	pH meter	Pre calibrated probe, meter	Field test
3	Color	Colorimeter	Calibrated with distilled water on every reading	Field test
4	Arsenic (Strip test)	Arsenic Field test Kit	60 ml sample analyzed with three reagents	Field test
5	Arsenic	ICPMS	100 ml sample digested in HNO_3	IIC IITR
6	Iron	ICPMS	100 ml sample digested in HNO_3	IIC IITR
7	Manganese	ICPMS	100 ml sample digested in HNO_3	IIC IITR
8	Copper	ICPMS	100 ml sample digested in HNO_3	IIC IITR
9	Zinc	ICPMS	100 ml sample digested in HNO_3	IIC IITR
10	Nitrate	Ion chromatography	100 ml sample in prerinsed container with Chromic acid, distilled water	EHL Lab
11	Alkalinity	Titration	pre-rinsed polyethylene container	EHL Lab
12	Hardness	Titration	pre-rinsed polyethylene container	EHL Lab
13	Chloride	Ion Chromatography	pre-rinsed polyethylene container	EHL Lab
14	Fluoride	Ion Chromatography	prerinsed polyethylene container	EHL Lab
15	Sulfate	Ion Chromatography	prerinsed polyethylene container	EHL Lab
16	Calcium	Ion Chromatography	prerinsed polyethylene container	EHL Lab
17	Magnesium	Ion Chromatography	pre-rinsed polyethylene container	EHL Lab
18	Silica	Spectrophotometer	pre-rinsed polyethylene container	EHL Lab
19	Orthophosphate	Spectrophotometer	pre-rinsed polyethylene container	EHL Lab

Appendix C

Questionnaire for data collection

1. Location of Plant			
2. Contact Address:			
3. What is the type of Plant			
(a) Adsorption	(b)Co-precipitation	(c) oxidation and filtration	(d) Ion exchange
Other:			
4. What is the Process Flowchart/Treatment Scheme of plant?			
5. Operation time of Plant:			
6. Operational Since:			
7. Scale of use of Plant:			
a) Individual level	b) Community level	(c) Organizational level	(d) Other
8. What is the Design Capacity and flow rate of plant?			
Design Capacity			
Maximum flowrate			
Average flowrate			
Time of running			
Source of water			
9. Energy requirement of plant			
SN	Equipment used	Unit	Energy requirement
10. Regeneration/Backwash (please specify units)			
(a) What is the Regeneration media/resin used?			
(b) What is the Regeneration time?			
(c) What is the Regeneration flow rate?			

(d) What is the Quantity of regeneration media/resin used per regeneration cycle? What is the Solution Concentration (mass/mass)?			
(e) What is the Backwash Time?			
(f) What is the Backwash flow rate?			
(g) What is the Output between regeneration?			
11. Monitoring of the plant			
(i)Water Parameters Measured			
(a)Arsenic	(e)Total Nitrite	(i)Chloride	(m)Silica
(b)Arsenate [As (V)]	(f)pH	(j)Fluoride	(n)Sulfate
(c)Arsenite [As (III)]	(g)Iron	(k)Manganese	(o)Nitrate
(d)Orthophosphate	(h)Total Dissolved Solids	(l)Total Organic Carbon	
(ii)Frequency of water quality monitoring			
(iii)Lab Analysis and Lab facilities at site			
12. Maintenance			
(i)Type of maintenance Scheme:			
(ii)What is the breakdown time and frequency of breakdown?			
(ii)Skill level required for operation and maintenance and no. of workers			
(a) Unskilled	(b) Semi Skilled	(c) Skilled	(d) highly skilled
13. Infrastructure Requirements			
(i)Power (ii)Water	(iii)Other:		

14. What is Land Area occupied by the plant?	
15. What are the Construction/Installation Costs?	
16. What are the Maintenance Costs?	
17. Pre/post treatment	
(a)Is pre-oxidation of Arsenite to Arsenate required? Associated costs?	
(b)Is pH adjustment required? Associated costs?	
(c)Is pre-filtration required? Associated costs?	
18. Operation Costs? (Materials, Labor, Energy)	
19. What is the quantity of hazardous waste sludge/ material is produced? What is the method of its disposal? How and where it is transported?	
20. What are the potential environmental impacts from the treatment process?	
21. Can the quantities and hazard level of residuals be minimized?	
22. Do the public understand and trust the reliability and safety of the technology? Are locals satisfied with the setup?	
23. Does the influent water quality vary?	
24. Can the treatment system handle these variations?	
25. What is the Distribution Scheme of plant?	
26. What is the number of People/Households served by the plant? Does the number vary (If yes reasons)?	

Appendix D

S.N.	Plants	Location	Capacity	Technology Used	No. of Household served
	Bhagalpur, Nathnagar Block				
1	Gosaindashpur	25.25464 N, 86.88107 E	2 m^3/h	Adsorption by Activated Alumina	110
2	Haridaspur	25.2474 N, 86.90251 E	2 m^3/h	Adsorption by Activated Alumina	150
3	Raghoupur	25.25729 N, 86.89363 E	2 m^3/h	Adsorption by Activated Alumina	150
4	Madhawpur	25.25355 N, 86.8946 E	2 m^3/h	Adsorption by Activated Alumina	150
5	Mohdipur	25.2514 N, 86.92594 E	2 m^3/h	Adsorption by Activated Alumina	150
6	Shahpur	25.25144 N, 86.92569 E	2 m^3/h	Adsorption by Activated Alumina	80
7	Runuchak, Makandpur(Naya Tola)	25.246133 N, 86.87994 E	2 m^3/h	Adsorption by Activated Alumina	90
8	Runuchak, Makandpur(Purana Tola)	25.24618 N, 86.8763 E	2 m^3/h	Adsorption by Activated Alumina	200
	Bhojpur				
9	Mozimpur (Mitigation Plant)	25.686487 N, 84.586270 E	540 m^3/h	Coagulation and flocculation and filtration	40 villages multi supply scheme
	Buxar , Simri Block				
10	Tilak Rai Ka Hata, Simri	25.62094 N, 84.29656 E	0.8 m^3/h	Ion Exchange by HIAX resin	30
11	Khairapatti,Simri	25.68861 N, 84.29655 E	0.8 m^3/h	Adsorption by Activated Alumina	150
	Buxar, Berhampur Block				
12	Dhanchapara,Berhampur	25.64712 N, 84.10193 E	0.8 m^3/h	Hydrous Zirconium Cartridge filter	120
13	Sapahi,Berhampur	25.61772 N, 84.31992 E	0.8 m^3/h	Hydrous Zirconium Cartridge filter	95
14	Chaubeychak, Berhampur	25.61663 N, 84.3276 E	0.8 m^3/h	Hydrous Zirconium based Cartritdge filter	100
	Patna				
15	Maner, Patna	25.663890 N, 84.901672 E	7000 lpd	Ion Exchgange by HIAX resin	60

Appendix E

Water quality analysis

S.N.	Parameters	unit	Tilak Rai Ka Hata, Simri		KhairaPatti, Simri		Sapahi, Bramhpur		Dhanchapara, Bramhpur	
			Raw	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
1	Temperature	°C	27	27.8	26	27.2	28	28.6	26	26.5
2	Conductivity	µS/cm	1105	1120	719.5	710	742.5	688	745	746
3	pH		7.37	7.33	7.37	7.33	7.29	7.39	6.91	6.9
4	Color	Hazen Units	14	0	9	0	15	2	16	7
5	Arsenic (Strip test)	ppb	>50	<5	>100	<100	>5	>0	<5	<5
6	Arsenic	ppb	23.355	4.752	188.041	56.19	48.65	4.046	6.08	4.88
7	Iron	ppb	258.513	239.339	1446.803	591.595	622.187	128.279	184.762	160.153
8	Mangnese	ppb	79.546	4.975	66.928	111.84	10.255	20.408	13.661	13.274
9	Copper	ppb	318.145	7.158	1081.564	1.002	3390.992	1.601	232.471	124.94
10	Zinc	ppb	368.935	12.514	107.999	338.329	350.875	338.81	168.361	45.387
11	Alkalinity	ppb	380000	320000	380000	380000	480000	360000	340000	296000
12	Hardness	ppb	310000	170000	90000	80000	120000	70000	150000	100000
13	Chloride	ppb	25325	21440	4230	424	18672.5	17695	24190	16019
14	Flouride	ppb	360	0	0	0	670	520	600	430
15	Sulphate	ppb	37331.5	34205	2670	2420	6550	5755	6700	21800
16	Nitrate	ppb	1630	0	0	0	8785	8345	5560	5305
17	Calcium	ppb	3500	20600	27450	46500	8470	7575	39955	10310
18	Magnesium	ppb	1020	295	370	360	4125	45	615	9.5
19	Silica	ppb	33905.5	31511.8	30252	30708.7	34929.1	34692.9	37952.8	35700.8
20	Orthophosphate	ppb	4084.54	0	0	0	0	0	0	0
21	sodium	ppb	27895	27405	28820	23960	41865	39910	26415	21725
22	pottassium	ppb	6080	4495	5080	4950	4865	4920	6255	5670

Appendix F

Percentage Process impact calculations for Activated Alumina Plant Khairapatti

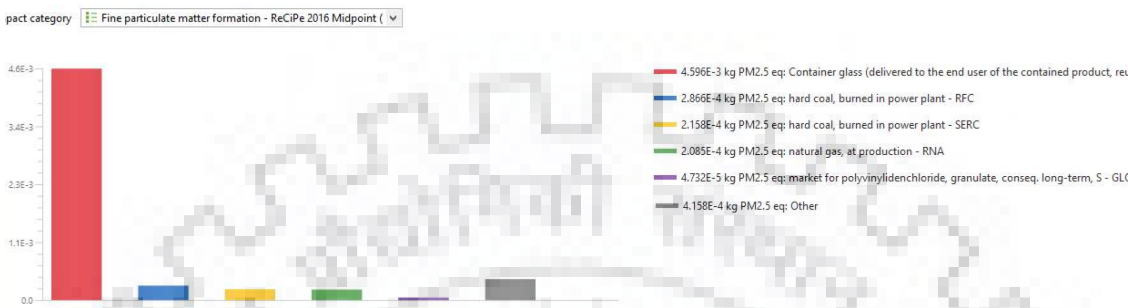
S.N	Impact Category	Electricity Solar %	Activated carbon%	Activated alumina%	CPVC pipes%	Gravel media %	Sand media%	PVC tanks %	FRP vessels %	Transportation%
1	Fine particulate matter formation	1.91	2.76	0.83	0.05	44.95	47.45	0.9	0.46	0.68
2	Fossil resource scarcity	26.6	26.96	11.58	2.1	0	0	10.78	9.39	12.58
3	Freshwater ecotoxicity	60.06	10.7	14.43	0.29	1.42	1.5	5.88	2.38	3.35
4	Freshwater eutrophication	44.77	25.45	8.39	0.34	4.86	5.13	4.78	4.55	1.73
5	Global warming	1.99	2.04	0.8	0.09	45.28	47.49	0.71	0.53	0.77
6	Human carcinogenic toxicity	17.69	6.32	62.08	0.39	0.05	0.06	9.36	1.51	2.54
7	Human non-carcinogenic toxicity	70.74	10.88	2.96	0.22	2.16	2.28	3.54	2.56	4.66
8	Ionizing radiation	3.68	0.75	0.75	0.05	45.26	47.77	0.6	0.84	0.42
9	Land use	41.86	0.63	7.5	1.95	0	0	14.13	4.93	11.06
10	Marine ecotoxicity	66.33	18.57	7.98	0.23	2.26	2.39	3.69	2.48	4.31
11	Marine eutrophication	8.06	10.32	0.55	0.11	42.2	45.54	0.65	0.77	0.22
12	Mineral resource scarcity	19.15	2.91	28.94	0.05	24.03	25.36	0.28	0.8	1.05
13	Ozone formation, Human health	2	0.35	1.09	0.1	44.16	46.62	0.77	0.51	2.51
14	Ozone formation, Terrestrial ecosystems	2.1	2.23	1.11	0.11	44.07	46.52	0.8	0.53	2.54
15	Stratospheric ozone depletion	4.16	2.23	0.89	0.12	25.12	26.51	17.52	22.09	1.58
16	Terrestrial acidification	1.55	2.02	0.62	0.05	45.73	48.26	0.69	0.41	0.56
17	Terrestrial ecotoxicity	47.6	2.13	4.44	0.07	21.05	22.22	0.45	0.77	2.04
18	Water consumption	47.6	1.37	4.44	0.07	21.05	22.22	0.45	0.77	2.04

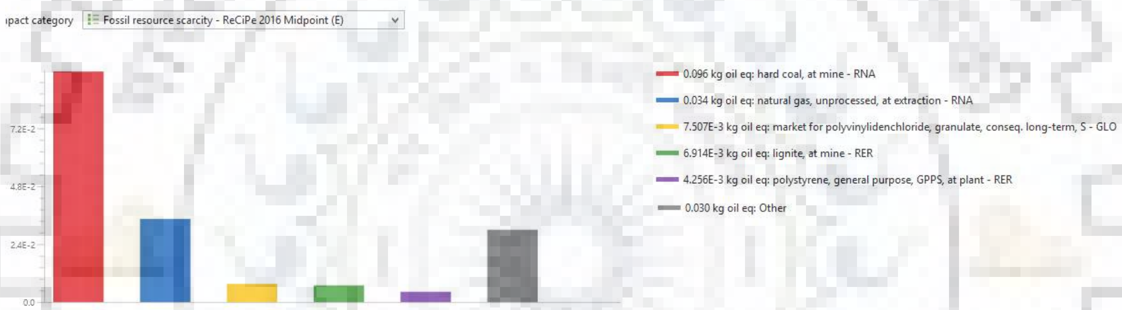
Percentage Process impact calculations for HIAX Plant Tilak Rai ka Hata

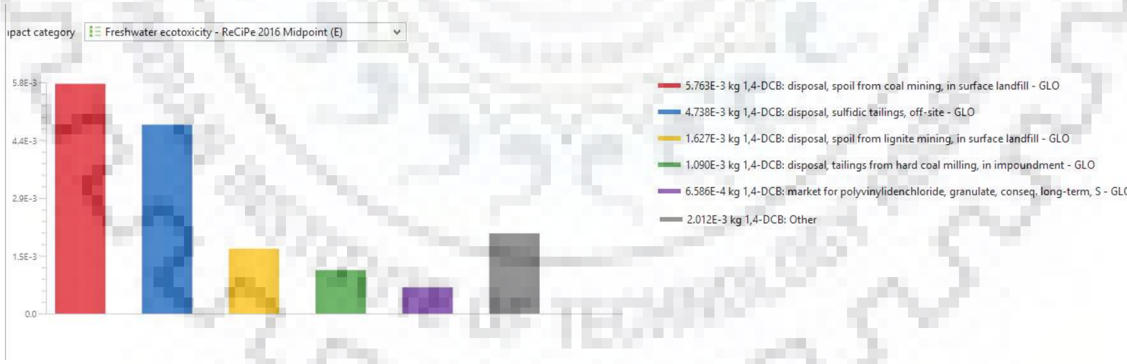
S.N.	Impact Category	Electricity Mix Grid%	Anion resin%	CPVC pipes%	Gravel media%	Sand media%	PVC Tanks%	HCL%	FRP vessels%	Transportation%
1	Fine particulate matter formation	18.49	0.33	0.025	38.75	40.9	0.97	0.03	0.16	0.35
2	Fossil resource scarcity	83.43	6.46	0.42	0	0	5.19	0.16	1.44	2.91
3	Freshwater ecotoxicity	88.04	2.38	0.1	0.99	1.05	5.1	0.27	0.66	1.4
4	Freshwater eutrophication	90.95	1.93	0.06	1.77	1.86	2.15	0.25	0.65	0.37
5	Global warming	15.35	0.76	0.04	40.11	42.33	0.78	0.03	0.18	0.41
6	Human carcinogenic toxicity	83.83	1.85	0.2	0.06	0.06	11.7	0.18	0.6	1.53
7	Human non-carcinogenic toxicity	89.12	2.45	0.07	1.37	1.44	2.77	0.29	0.64	1.76
8	Ionizing radiation	24.45	0.79	0.02	35.81	37.8	0.59	0.09	0.26	0.2
9	Land use	88.44	2.12	0.34	0	0	5.95	0.25	0.66	2.24
10	Marine ecotoxicity	88.67	2.43	0.08	1.51	1.6	3.06	0.28	0.66	1.72
11	Marine eutrophication	23.32	3.2	0.05	35.18	37.13	0.67	0.1	0.25	0.11
12	Mineral resource scarcity	18.78	1.87	0.04	37.51	39.6	0.53	0.2	0.5	0.98
13	Ozone formation, Human health	13.68	0.46	0.05	40.55	42.81	0.07	0.02	0.19	1.38
14	Ozone formation, Terrestrial ecosystems	13.72	0.47	0.05	40.49	42.74	0.91	0.02	0.19	1.39
15	Stratospheric ozone depletion	10.54	54.52	0.03	10.55	11.13	9.12	0.05	3.67	0.39
16	Terrestrial acidification	18.03	0.29	0.02	39.15	41.33	0.73	0	0.14	0.29
17	Terrestrial ecotoxicity	29.51	1.35	0.05	32	33.77	0.84	0.16	0.46	1.85
18	Water consumption	66.55	1.81	0.05	-0.14	-0.15	1.14	0.18	0.49	1.51

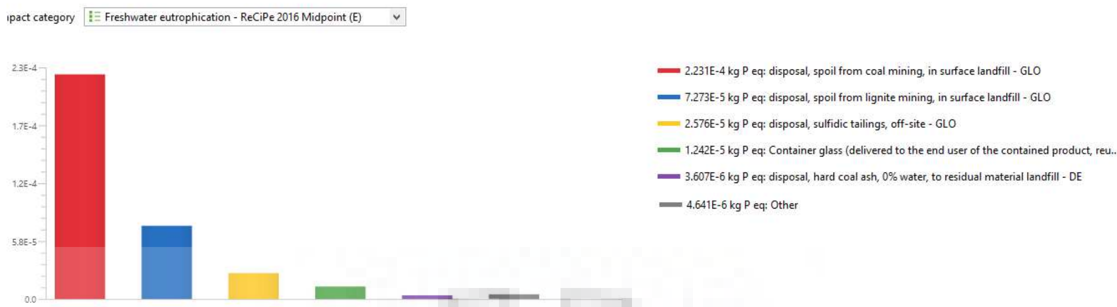
Appendix G

To 5 impact contributors Activated Alumina Plant Khairapatti, associated process





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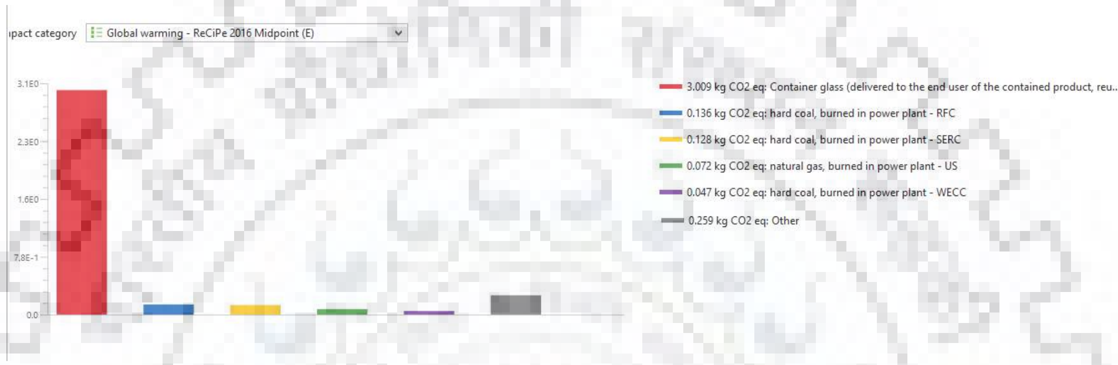
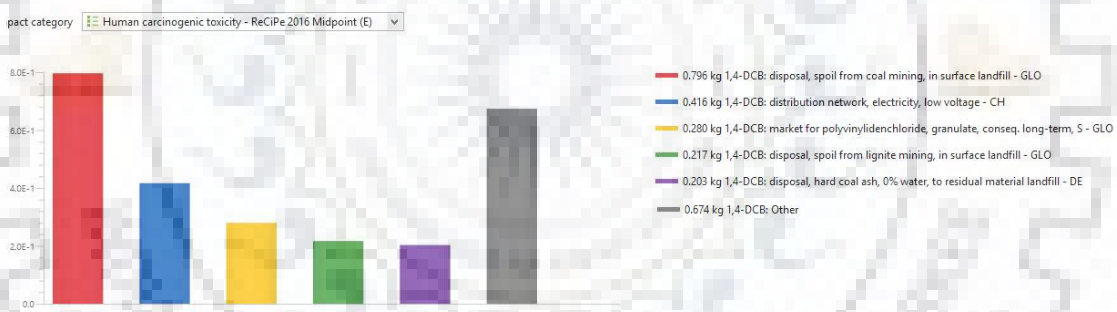
Freshwater eutrophication - ReCiPe 2016 Midpoint (E)
2.3E-4
1.7E-4
1.2E-4
5.8E-5
0.0
2.231E-4 kg P eq: disposal, spoil from coal mining, in surface landfill - GLO
7.273E-5 kg P eq: disposal, spoil from lignite mining, in surface landfill - GLO
2.576E-5 kg P eq: disposal, sulfidic tailings, off-site - GLO
1.242E-5 kg P eq: Container glass (delivered to the end user of the contained product, reu...
3.607E-6 kg P eq: disposal, hard coal ash, 0% water, to residual material landfill - DE
4.641E-6 kg P eq: Other


pact category
Global warming - ReCiPe 2016 Midpoint (E)
3.1E0
2.3E0
1.6E0
7.8E-1
0.0
3.009 kg CO2 eq: Container glass (delivered to the end user of the contained product, reu...
0.136 kg CO2 eq: hard coal, burned in power plant - RFC
0.128 kg CO2 eq: hard coal, burned in power plant - SERC
0.072 kg CO2 eq: natural gas, burned in power plant - US
0.047 kg CO2 eq: hard coal, burned in power plant - WECC
0.259 kg CO2 eq: Other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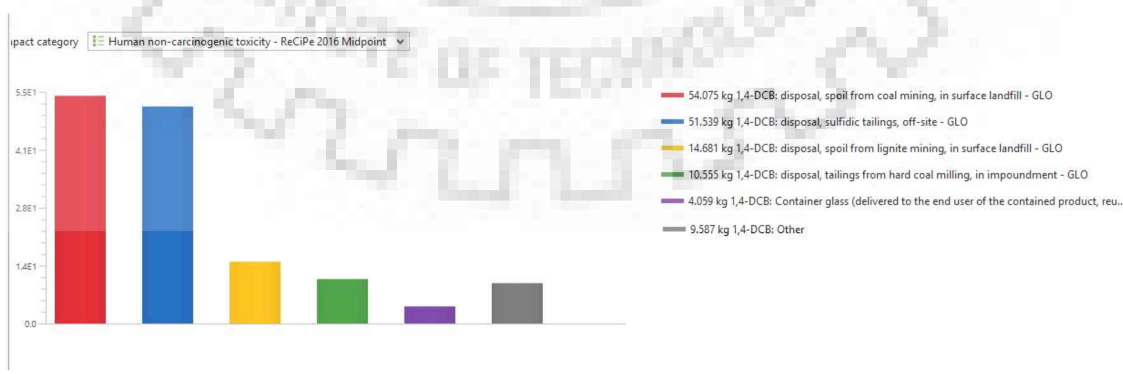
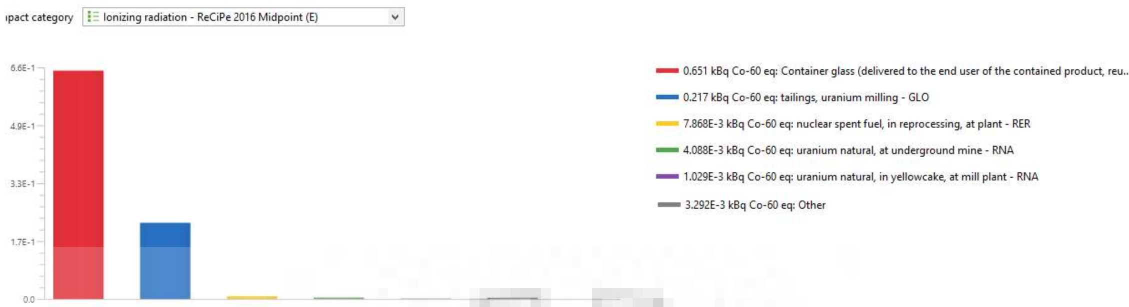
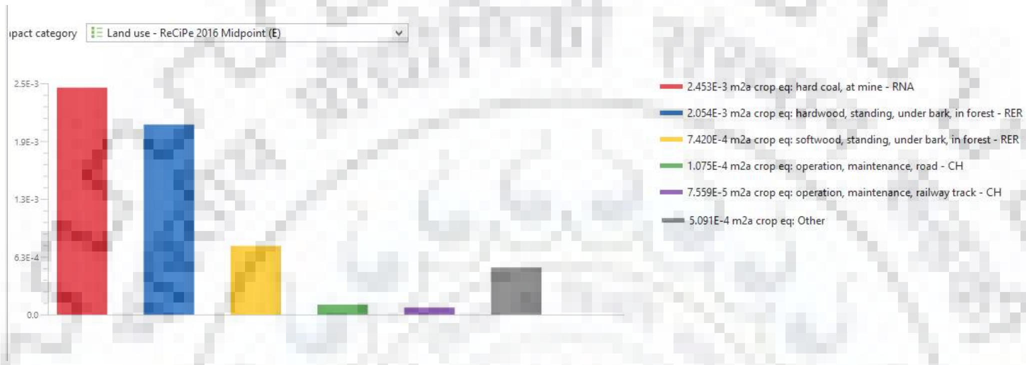
Human carcinogenic toxicity - ReCiPe 2016 Midpoint (E)
8.0E-1
6.0E-1
4.0E-1
2.0E-1
0.0
0.796 kg 1,4-DCB: disposal, spoil from coal mining, in surface landfill - GLO
0.416 kg 1,4-DCB: distribution network, electricity, low voltage - CH
0.280 kg 1,4-DCB: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
0.217 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
0.203 kg 1,4-DCB: disposal, hard coal ash, 0% water, to residual material landfill - DE
0.674 kg 1,4-DCB: Other


pact category
Human non-carcinogenic toxicity - ReCiPe 2016 Midpoint
5.5E1
4.1E1
2.8E1
1.4E1
0.0
54.075 kg 1,4-DCB: disposal, spoil from coal mining, in surface landfill - GLO
51.539 kg 1,4-DCB: disposal, sulfidic tailings, off-site - GLO
14.681 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
10.555 kg 1,4-DCB: disposal, tailings from hard coal milling, in impoundment - GLO
4.059 kg 1,4-DCB: Container glass (delivered to the end user of the contained product, reu...
9.587 kg 1,4-DCB: Other


Impact category
Ionizing radiation - ReCiPe 2016 Midpoint (E)
0.651 kBq Co-60 eq: Container glass (delivered to the end user of the contained product, reu...
0.217 kBq Co-60 eq: tailings, uranium milling - GLO
7.868E-3 kBq Co-60 eq: nuclear spent fuel, in reprocessing, at plant - RER
4.088E-3 kBq Co-60 eq: uranium natural, at underground mine - RNA
1.029E-3 kBq Co-60 eq: uranium natural, in yellowcake, at mill plant - RNA
3.292E-3 kBq Co-60 eq: Other


Impact category
Land use - ReCiPe 2016 Midpoint (E)
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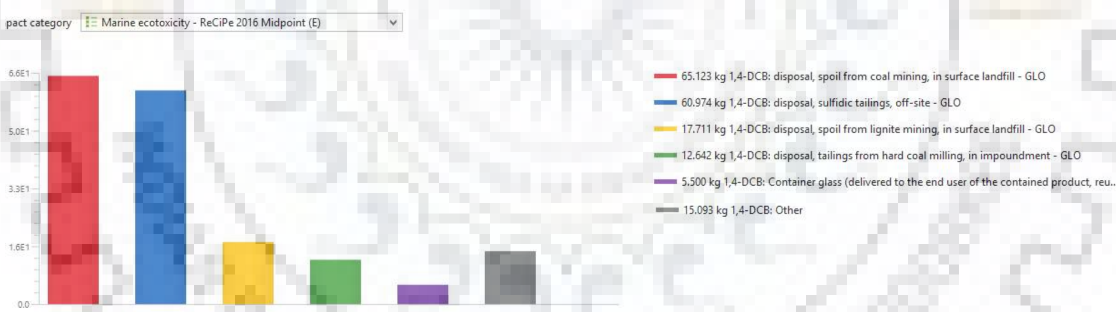
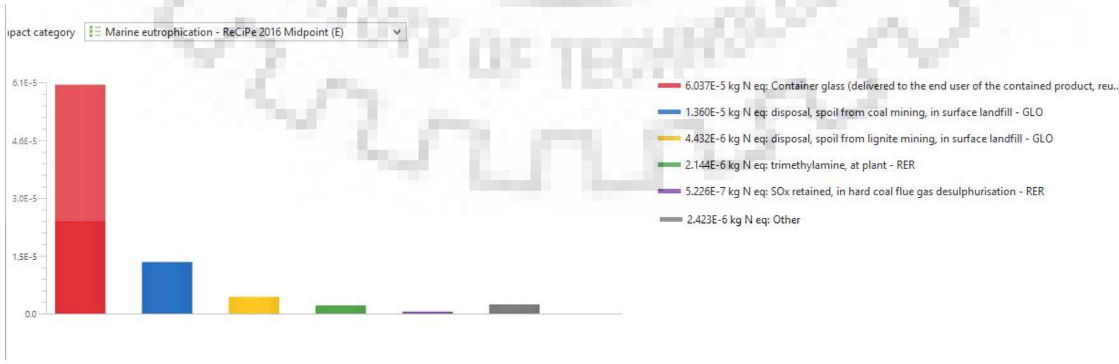
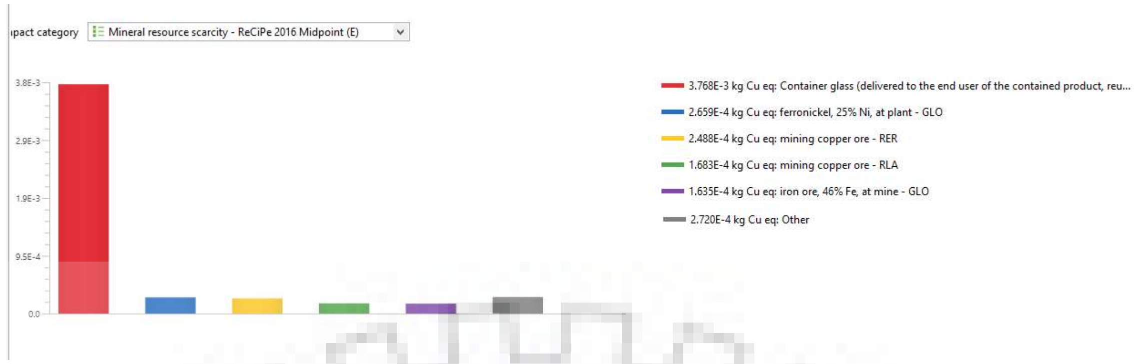
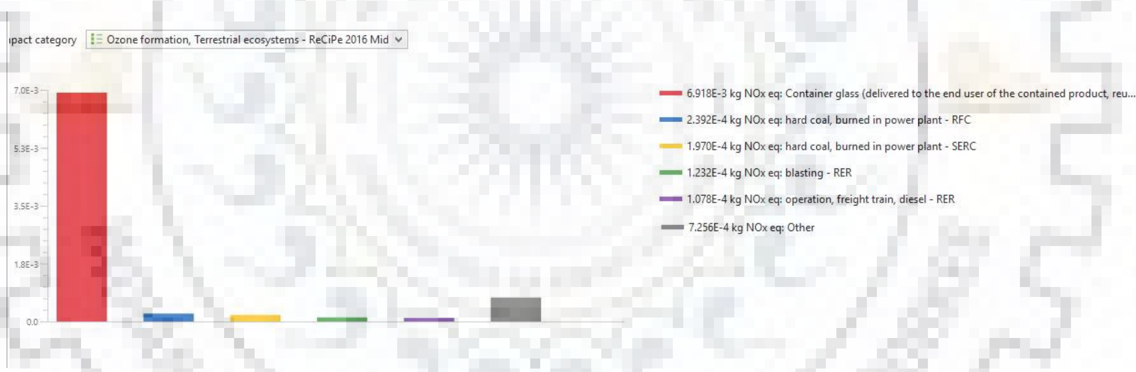
2.054E-3 m2a crop eq: hardwood, standing, under bark, in forest - RER
7.420E-4 m2a crop eq: softwood, standing, under bark, in forest - RER
1.075E-4 m2a crop eq: operation, maintenance, road - CH
7.559E-5 m2a crop eq: operation, maintenance, railway track - CH
5.091E-4 m2a crop eq: Other

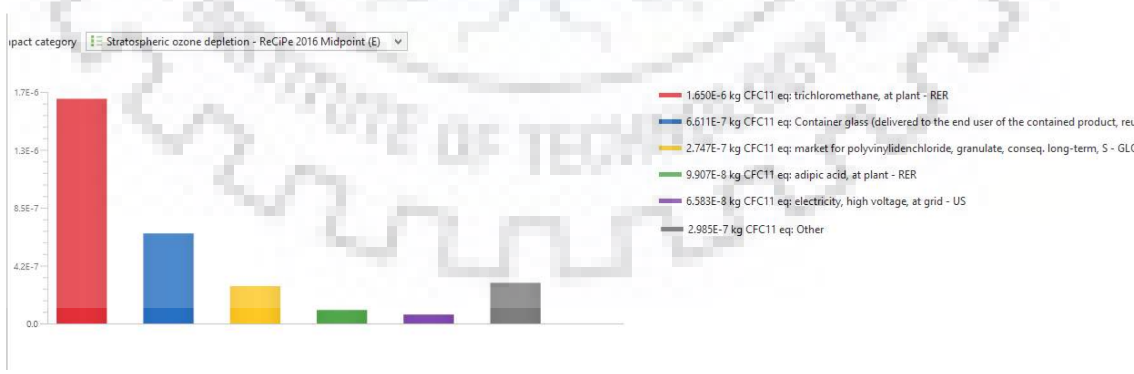

Impact category
Marine ecotoxicity - ReCiPe 2016 Midpoint (E)
65.123 kg 1,4-DCB: disposal, spoil from coal mining, in surface landfill - GLO
60.974 kg 1,4-DCB: disposal, sulfidic tailings, off-site - GLO
17.711 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
12.642 kg 1,4-DCB: disposal, tailings from hard coal milling, in impoundment - GLO
5.500 kg 1,4-DCB: Container glass (delivered to the end user of the contained product, reu...
15.093 kg 1,4-DCB: Other

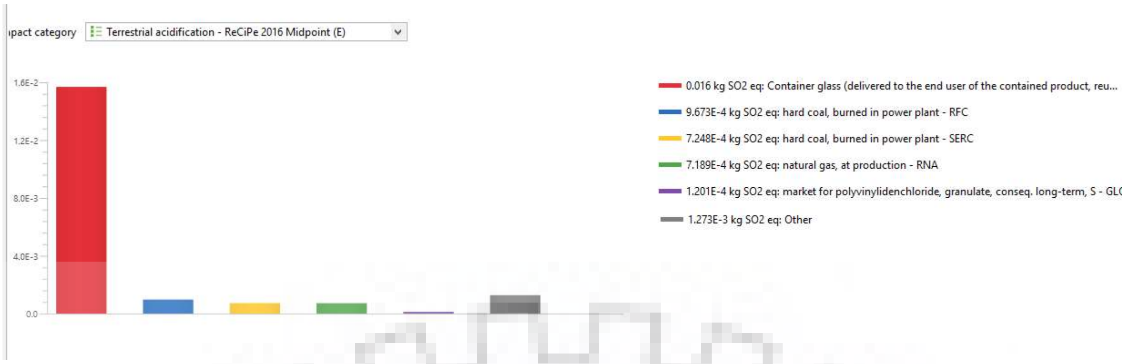

Impact category
Marine eutrophication - ReCiPe 2016 Midpoint (E)
6.037E-5 kg N eq: Container glass (delivered to the end user of the contained product, reu...
1.360E-5 kg N eq: disposal, spoil from coal mining, in surface landfill - GLO
4.432E-6 kg N eq: disposal, spoil from lignite mining, in surface landfill - GLO
2.144E-6 kg N eq: trimethylamine, at plant - RER
5.226E-7 kg N eq: SOx retained, in hard coal flue gas desulphurisation - RER
2.423E-6 kg N eq: Other

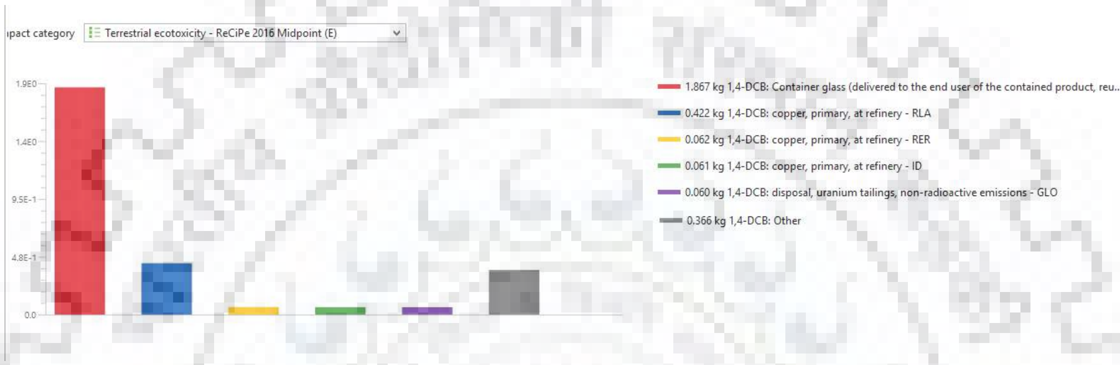

pact category
Mineral resource scarcity - ReCiPe 2016 Midpoint (E)
3.8E-3
2.9E-3
1.9E-3
9.5E-4
0.0
3.768E-3 kg Cu eq: Container glass (delivered to the end user of the contained product, reu...
2.659E-4 kg Cu eq: ferronickel, 25% Ni, at plant - GLO
2.488E-4 kg Cu eq: mining copper ore - RER
1.683E-4 kg Cu eq: mining copper ore - RLA
1.635E-4 kg Cu eq: iron ore, 46% Fe, at mine - GLO
2.720E-4 kg Cu eq: Other

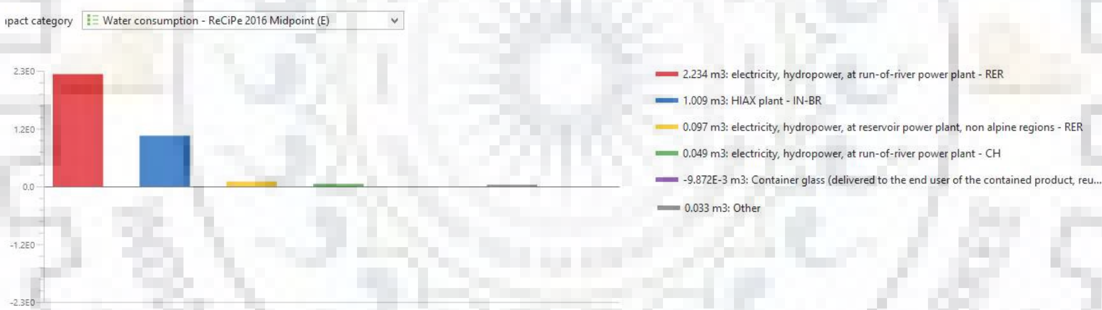

pact category
Ozone formation, Human health - ReCiPe 2016 Midpoint (E
6.9E-3
5.2E-3
3.5E-3
1.7E-3
0.0
6.882E-3 kg NOx eq: Container glass (delivered to the end user of the contained product, reu...
2.389E-4 kg NOx eq: hard coal, burned in power plant - RFC
1.967E-4 kg NOx eq: hard coal, burned in power plant - SERC
1.209E-4 kg NOx eq: blasting - RER
1.068E-4 kg NOx eq: operation, freight train, diesel - RER
7.103E-4 kg NOx eq: Other


pact category
Ozone formation, Terrestrial ecosystems - ReCiPe 2016 Mid
7.0E-3
5.3E-3
3.5E-3
1.8E-3
0.0
6.918E-3 kg NOx eq: Container glass (delivered to the end user of the contained product, reu...
2.392E-4 kg NOx eq: hard coal, burned in power plant - RFC
1.970E-4 kg NOx eq: hard coal, burned in power plant - SERC
1.232E-4 kg NOx eq: blasting - RER
1.078E-4 kg NOx eq: operation, freight train, diesel - RER
7.256E-4 kg NOx eq: Other

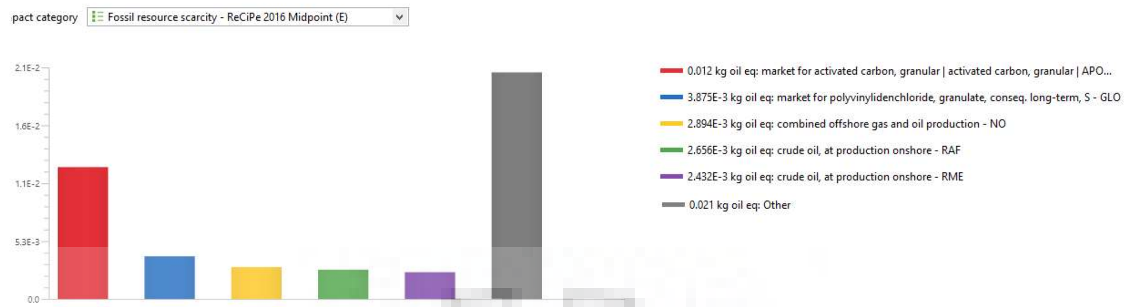

pact category
Stratospheric ozone depletion - ReCiPe 2016 Midpoint (E)
1.7E-6
1.3E-6
8.5E-7
4.2E-7
0.0
1.650E-6 kg CFC11 eq: trichloromethane, at plant - RER
6.611E-7 kg CFC11 eq: Container glass (delivered to the end user of the contained product, reu
2.747E-7 kg CFC11 eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLC
9.907E-8 kg CFC11 eq: adipic acid, at plant - RER
6.583E-8 kg CFC11 eq: electricity, high voltage, at grid - US
2.985E-7 kg CFC11 eq: Other

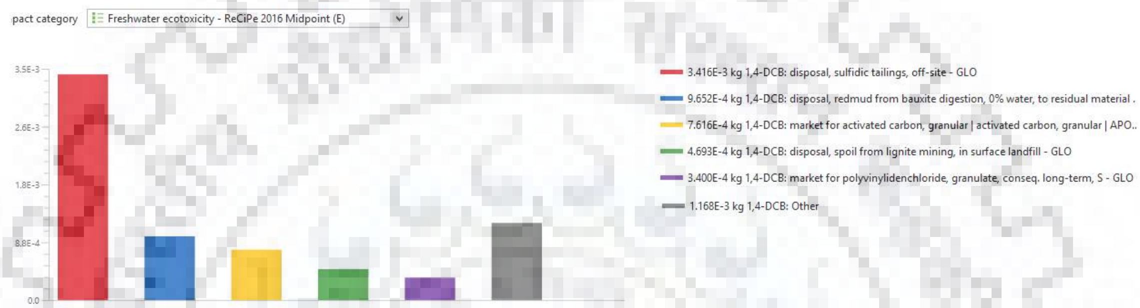


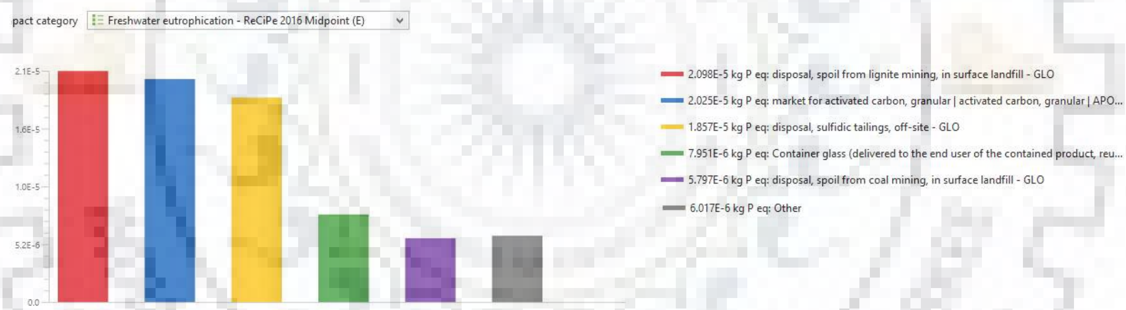


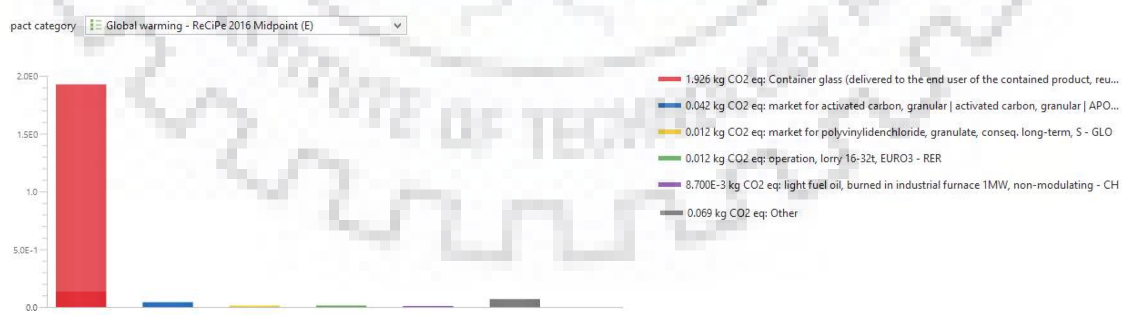


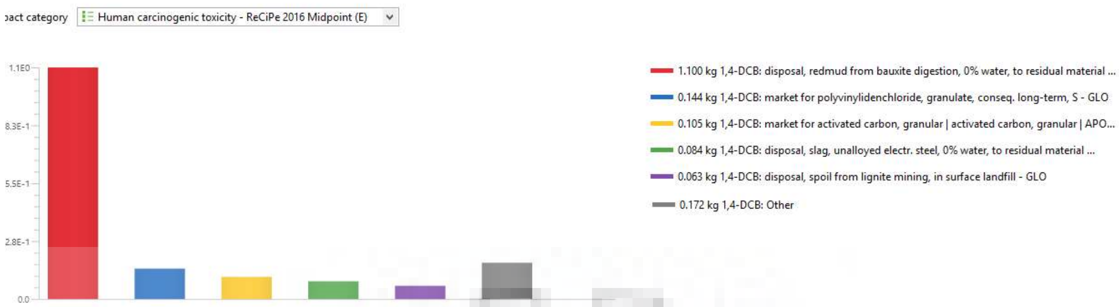
To 5 impact contributors HIAX plant, Tilak Rai Ka Hata associated process

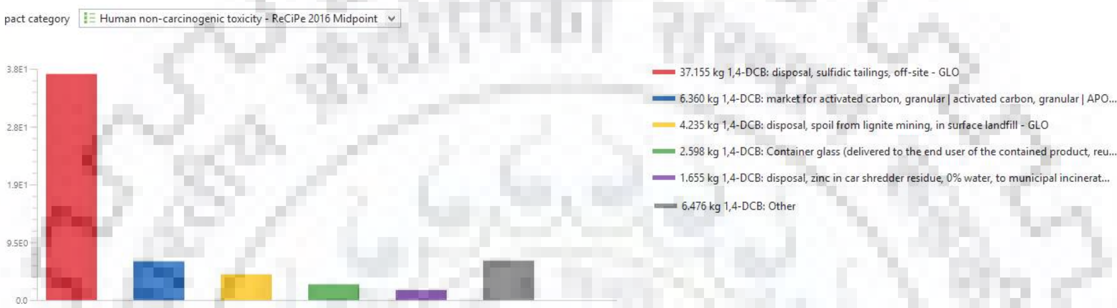

pact category
Fossil resource scarcity - ReCiPe 2016 Midpoint (E)
0.012 kg oil eq: market for activated carbon, granular | activated carbon, granular | APO...
3.875E-3 kg oil eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
2.894E-3 kg oil eq: combined offshore gas and oil production - NO
2.656E-3 kg oil eq: crude oil, at production onshore - RAF
2.432E-3 kg oil eq: crude oil, at production onshore - RME
0.021 kg oil eq: Other

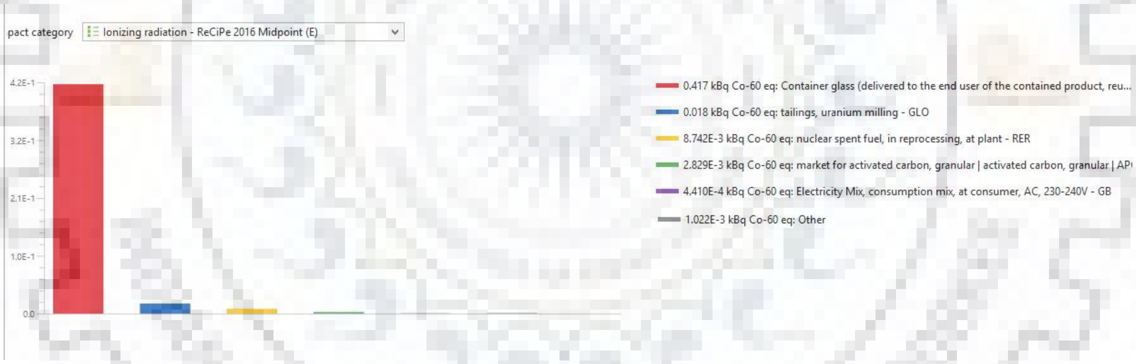

pact category
Freshwater ecotoxicity - ReCiPe 2016 Midpoint (E)
3.416E-3 kg 1,4-DCB: disposal, sulfidic tailings, off-site - GLO
9.652E-4 kg 1,4-DCB: disposal, redmud from bauxite digestion, 0% water, to residual material .
7.616E-4 kg 1,4-DCB: market for activated carbon, granular | activated carbon, granular | APO..
4.693E-4 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
3.400E-4 kg 1,4-DCB: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
1.168E-3 kg 1,4-DCB: Other

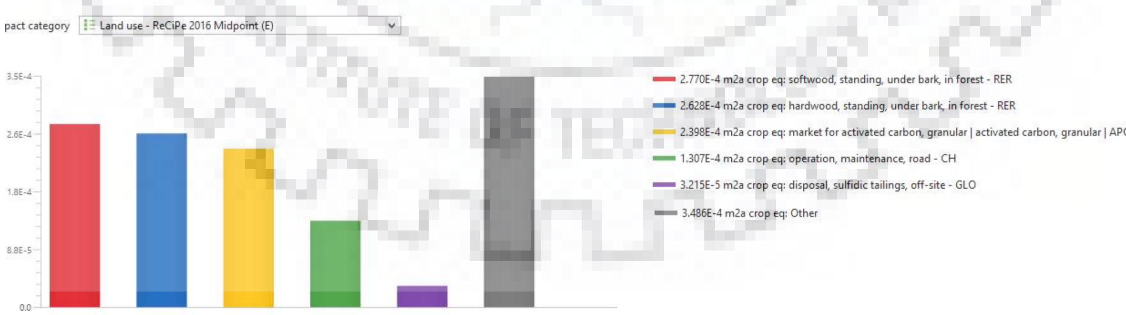

pact category
Freshwater eutrophication - ReCiPe 2016 Midpoint (E)
2.098E-5 kg P eq: disposal, spoil from lignite mining, in surface landfill - GLO
2.025E-5 kg P eq: market for activated carbon, granular | activated carbon, granular | APO...
1.857E-5 kg P eq: disposal, sulfidic tailings, off-site - GLO
7.951E-6 kg P eq: Container glass (delivered to the end user of the contained product, reu...
5.797E-6 kg P eq: disposal, spoil from coal mining, in surface landfill - GLO
6.017E-6 kg P eq: Other

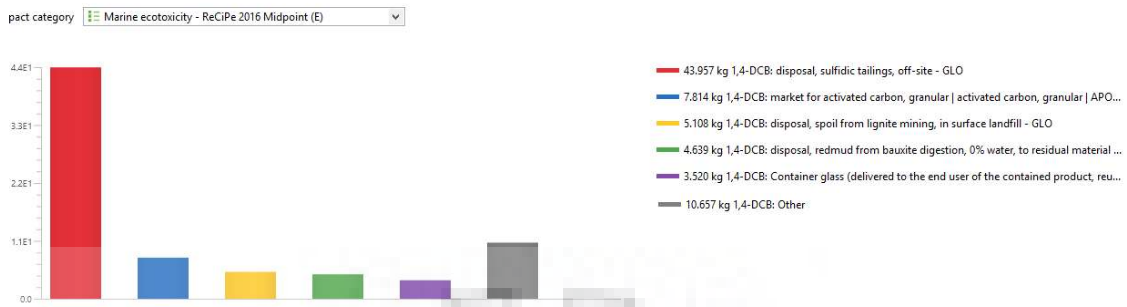

pact category
Global warming - ReCiPe 2016 Midpoint (E)
1.926 kg CO2 eq: Container glass (delivered to the end user of the contained product, reu...
0.042 kg CO2 eq: market for activated carbon, granular | activated carbon, granular | APO...
0.012 kg CO2 eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
0.012 kg CO2 eq: operation, lorry 16-32t, EURO3 - RER
8.700E-3 kg CO2 eq: light fuel oil, burned in industrial furnace 1MW, non-modulating - CH
0.069 kg CO2 eq: Other

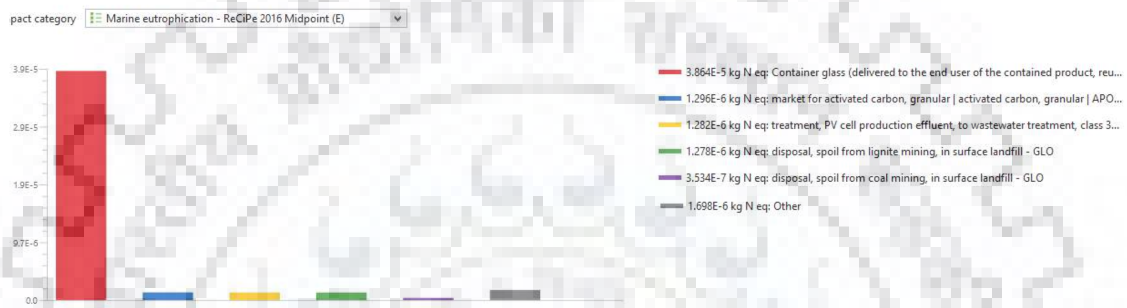

pact category
Human carcinogenic toxicity - ReCiPe 2016 Midpoint (E)
1.1E0
8.3E-1
5.5E-1
2.8E-1
0.0
1.100 kg 1,4-DCB: disposal, redmud from bauxite digestion, 0% water, to residual material ...
0.144 kg 1,4-DCB: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
0.105 kg 1,4-DCB: market for activated carbon, granular | activated carbon, granular | APO...
0.084 kg 1,4-DCB: disposal, slag, unalloyed electr. steel, 0% water, to residual material ...
0.063 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
0.172 kg 1,4-DCB: Other

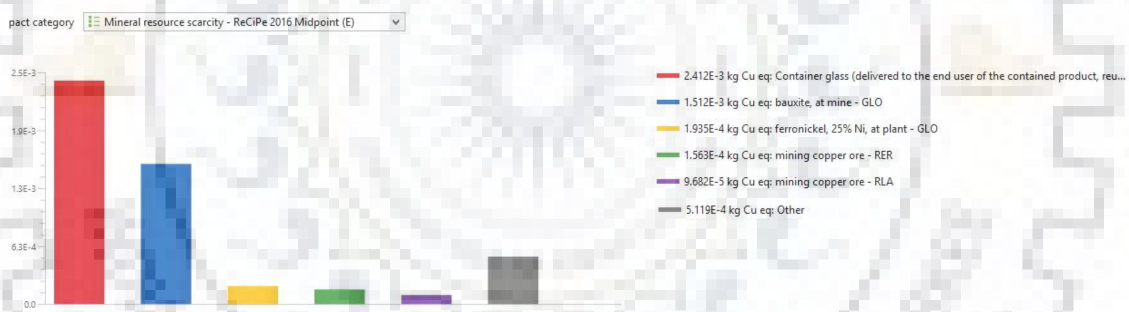

pact category
Human non-carcinogenic toxicity - ReCiPe 2016 Midpoint
3.8E1
2.8E1
1.9E1
9.5E0
0.0
37.155 kg 1,4-DCB: disposal, sulfidic tailings, off-site - GLO
6.360 kg 1,4-DCB: market for activated carbon, granular | activated carbon, granular | APO...
4.235 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
2.598 kg 1,4-DCB: Container glass (delivered to the end user of the contained product, reu...
1.655 kg 1,4-DCB: disposal, zinc in car shredder residue, 0% water, to municipal incinerat...
6.476 kg 1,4-DCB: Other

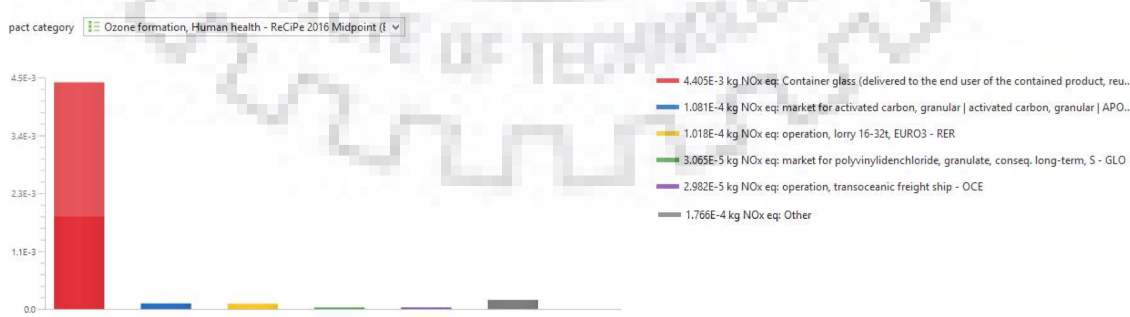

pact category
Ionizing radiation - ReCiPe 2016 Midpoint (E)
4.2E-1
3.2E-1
2.1E-1
1.0E-1
0.0
0.417 kBq Co-60 eq: Container glass (delivered to the end user of the contained product, reu...
0.018 kBq Co-60 eq: tailings, uranium milling - GLO
8.742E-3 kBq Co-60 eq: nuclear spent fuel, in reprocessing, at plant - RER
2.829E-3 kBq Co-60 eq: market for activated carbon, granular | activated carbon, granular | AP
4.410E-4 kBq Co-60 eq: Electricity Mix, consumption mix, at consumer, AC, 230-240V - GB
1.022E-3 kBq Co-60 eq: Other


pact category
Land use - ReCiPe 2016 Midpoint (E)
3.5E-4
2.6E-4
1.8E-4
8.8E-5
0.0
2.770E-4 m2a crop eq: softwood, standing, under bark, in forest - RER
2.628E-4 m2a crop eq: hardwood, standing, under bark, in forest - RER
2.398E-4 m2a crop eq: market for activated carbon, granular | activated carbon, granular | APC
1.307E-4 m2a crop eq: operation, maintenance, road - CH
3.215E-5 m2a crop eq: disposal, sulfidic tailings, off-site - GLO
3.486E-4 m2a crop eq: Other

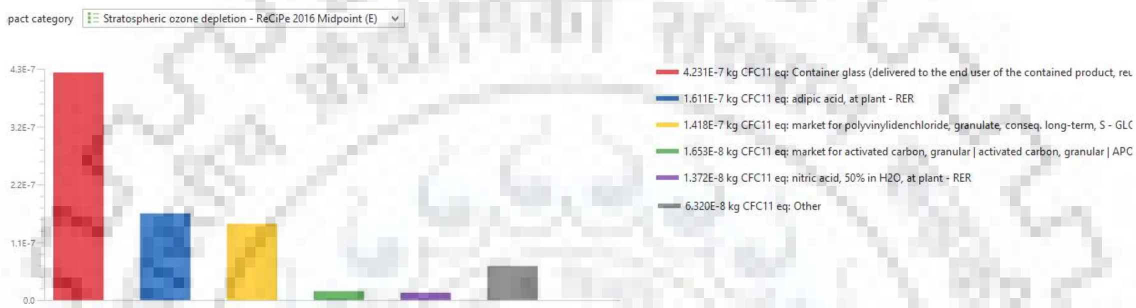

pact category
Marine ecotoxicity - ReCiPe 2016 Midpoint (E)
4.4E1
3.3E1
2.2E1
1.1E1
0.0
43.957 kg 1,4-DCB: disposal, sulfidic tailings, off-site - GLO
7.814 kg 1,4-DCB: market for activated carbon, granular | activated carbon, granular | APO...
5.108 kg 1,4-DCB: disposal, spoil from lignite mining, in surface landfill - GLO
4.639 kg 1,4-DCB: disposal, redmud from bauxite digestion, 0% water, to residual material ...
3.520 kg 1,4-DCB: Container glass (delivered to the end user of the contained product, reu...
10.657 kg 1,4-DCB: Other

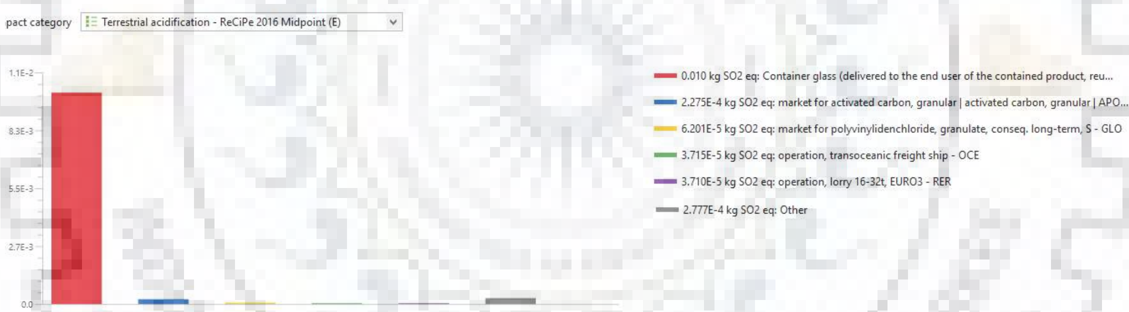

pact category
Marine eutrophication - ReCiPe 2016 Midpoint (E)
3.9E-5
2.9E-5
1.9E-5
9.7E-6
0.0
3.864E-5 kg N eq: Container glass (delivered to the end user of the contained product, reu...
1.296E-6 kg N eq: market for activated carbon, granular | activated carbon, granular | APO...
1.282E-6 kg N eq: treatment, PV cell production effluent, to wastewater treatment, class 3...
1.278E-6 kg N eq: disposal, spoil from lignite mining, in surface landfill - GLO
3.534E-7 kg N eq: disposal, spoil from coal mining, in surface landfill - GLO
1.698E-6 kg N eq: Other

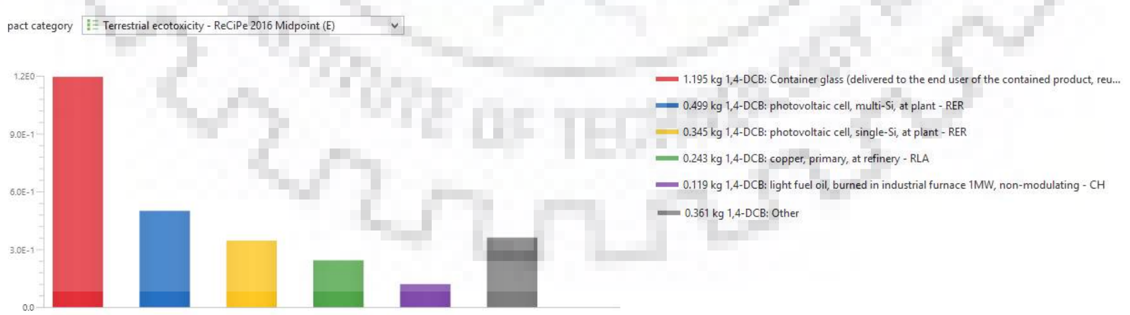

pact category
Mineral resource scarcity - ReCiPe 2016 Midpoint (E)
2.5E-3
1.9E-3
1.3E-3
6.3E-4
0.0
2.412E-3 kg Cu eq: Container glass (delivered to the end user of the contained product, reu...
1.512E-3 kg Cu eq: bauxite, at mine - GLO
1.935E-4 kg Cu eq: ferronickel, 25% Ni, at plant - GLO
1.563E-4 kg Cu eq: mining copper ore - RER
9.682E-5 kg Cu eq: mining copper ore - RLA
5.119E-4 kg Cu eq: Other

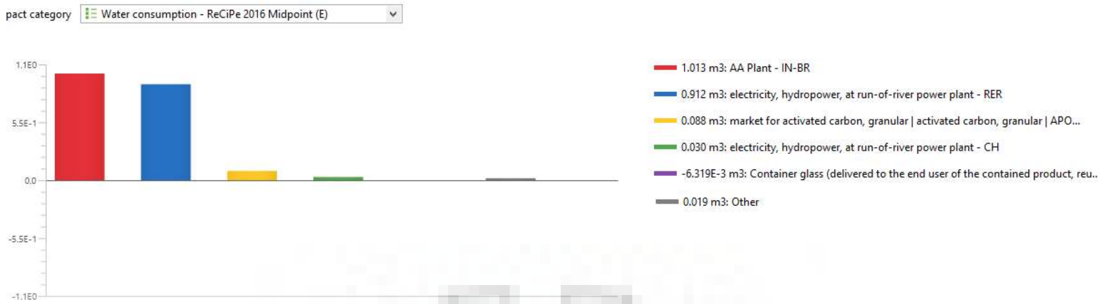

pact category
Ozone formation, Human health - ReCiPe 2016 Midpoint (
4.5E-3
3.4E-3
2.3E-3
1.1E-3
0.0
4.405E-3 kg NOx eq: Container glass (delivered to the end user of the contained product, reu...
1.081E-4 kg NOx eq: market for activated carbon, granular | activated carbon, granular | APO...
1.018E-4 kg NOx eq: operation, lorry 16-32t, EURO3 - RER
3.065E-5 kg NOx eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
2.982E-5 kg NOx eq: operation, transoceanic freight ship - OCE
1.766E-4 kg NOx eq: Other


pact category
Ozone formation, Terrestrial ecosystems - ReCiPe 2016 Mid
4.5E-3
3.4E-3
2.3E-3
1.1E-3
0.0
4.428E-3 kg NOx eq: Container glass (delivered to the end user of the contained product, reu...
1.091E-4 kg NOx eq: market for activated carbon, granular | activated carbon, granular | APO...
1.020E-4 kg NOx eq: operation, lorry 16-32t, EURO3 - RER
3.218E-5 kg NOx eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
2.997E-5 kg NOx eq: operation, transoceanic freight ship - OCE
1.865E-4 kg NOx eq: Other


pact category
Stratospheric ozone depletion - ReCiPe 2016 Midpoint (E)
4.3E-7
3.2E-7
2.2E-7
1.1E-7
0.0
4.231E-7 kg CFC11 eq: Container glass (delivered to the end user of the contained product, reu
1.611E-7 kg CFC11 eq: adipic acid, at plant - RER
1.418E-7 kg CFC11 eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
1.653E-8 kg CFC11 eq: market for activated carbon, granular | activated carbon, granular | APC
1.372E-8 kg CFC11 eq: nitric acid, 50% in H2O, at plant - RER
6.320E-8 kg CFC11 eq: Other


pact category
Terrestrial acidification - ReCiPe 2016 Midpoint (E)
1.1E-2
8.3E-3
5.5E-3
2.7E-3
0.0
0.010 kg SO2 eq: Container glass (delivered to the end user of the contained product, reu...
2.275E-4 kg SO2 eq: market for activated carbon, granular | activated carbon, granular | APO...
6.201E-5 kg SO2 eq: market for polyvinylidenchloride, granulate, conseq. long-term, S - GLO
3.715E-5 kg SO2 eq: operation, transoceanic freight ship - OCE
3.710E-5 kg SO2 eq: operation, lorry 16-32t, EURO3 - RER
2.777E-4 kg SO2 eq: Other


pact category
Terrestrial ecotoxicity - ReCiPe 2016 Midpoint (E)
1.2E0
9.0E-1
6.0E-1
3.0E-1
0.0
1.195 kg 1,4-DCB: Container glass (delivered to the end user of the contained product, reu...
0.499 kg 1,4-DCB: photovoltaic cell, multi-Si, at plant - RER
0.345 kg 1,4-DCB: photovoltaic cell, single-Si, at plant - RER
0.243 kg 1,4-DCB: copper, primary, at refinery - RLA
0.119 kg 1,4-DCB: light fuel oil, burned in industrial furnace 1MW, non-modulating - CH
0.361 kg 1,4-DCB: Other



Appendix H

Process flow contributions to impact categories HIAX plant, Tilak Rai Ka Hata

Fine particulate matter formation			
Process	**contribution**	**Amount**	**Unit**
Sand 0/2, production mix, at plant, wet and dry quarry, undried	40.90%	0.00236	kg PM2.5 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	38.75%	0.00224	kg PM2.5 eq
electricity, low voltage, at grid	18.49%	0.00107	kg PM2.5 eq
PVC tanks - IN-BR	0.97%	5.57E-05	kg PM2.5 eq
transport, lorry 16-32t	0.35%	2.02E-05	kg PM2.5 eq
anionic resin, at plant	0.33%	1.92E-05	kg PM2.5 eq
FRP vessel hand rolled - IN-WB	0.16%	9.01E-06	kg PM2.5 eq
hydrochloric acid, 30% in H2O, at plant	0.03%	1.45E-06	kg PM2.5 eq
CPVC pipes - IN-BR	0.02%	1.32E-06	kg PM2.5 eq
Fossil resource scarcity			
electricity, low voltage, at grid	83.43%	0.14905	kg oil eq
anionic resin, at plant	6.46%	0.01154	kg oil eq
PVC tanks - IN-BR	5.19%	0.00927	kg oil eq
transport, lorry 16-32t,	2.91%	0.0052	kg oil eq
FRP vessel hand rolled - IN-WB	1.44%	0.00257	kg oil eq
CPVC pipes - IN-BR	0.42%	0.00075	kg oil eq
hydrochloric acid, 30% in H2O, at plant	0.16%	0.00028	kg oil eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.00%	0	kg oil eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	0.00%	0	kg oil eq
Freshwater ecotoxicity			
electricity, low voltage, at grid	88.04%	0.01399	kg 1,4-DCB
PVC tanks - IN-BR	5.10%	0.00081	kg 1,4-DCB
anionic resin, at plant	2.38%	0.00038	kg 1,4-DCB
transport, lorry 16-32t	1.40%	0.00022	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	1.05%	0.00017	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.99%	0.00016	kg 1,4-DCB

FRP vessel hand rolled - IN-WB	0.66%	0.0001	kg 1,4-DCB
hydrochloric acid, 30% in H2O, at plant	0.27%	4.28E-05	kg 1,4-DCB
CPVC pipes - IN-BR	0.10%	1.64E-05	kg 1,4-DCB
Freshwater eutrophication			
electricity, low voltage, at grid	90.95%	0.00031	kg P eq
PVC tanks - IN-BR	2.15%	7.36E-06	kg P eq
anionic resin, at plant	1.93%	6.60E-06	kg P eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	1.86%	6.38E-06	kg P eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	1.77%	6.04E-06	kg P eq
FRP vessel hand rolled - IN-WB	0.65%	2.24E-06	kg P eq
transport, lorry 16-32t,	0.37%	1.28E-06	kg P eq
hydrochloric acid, 30% in H2O, at plant	0.25%	8.64E-07	kg P eq
CPVC pipes - IN-BR	0.06%	2.18E-07	kg P eq
Global warming			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	42.33%	1.54528	kg CO2 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	40.11%	1.46399	kg CO2 eq
electricity, low voltage, at grid	15.35%	0.56048	kg CO2 eq
PVC tanks - IN-BR	0.78%	0.02862	kg CO2 eq
anionic resin, at plant	0.76%	0.02785	kg CO2 eq
transport, lorry 16-32t,	0.41%	0.01493	kg CO2 eq
FRP vessel hand rolled - IN-WB	0.18%	0.00675	kg CO2 eq
CPVC pipes - IN-BR	0.04%	0.0015	kg CO2 eq
hydrochloric acid, 30% in H2O, at plant	0.03%	0.00092	kg CO2 eq
Human carcinogenic toxicity			
electricity, low voltage, at grid	83.83%	2.1677	kg 1,4-DCB
PVC tanks - IN-BR	11.70%	0.30255	kg 1,4-DCB
anionic resin, at plant	1.85%	0.04795	kg 1,4-DCB
transport, lorry 16-32t	1.53%	0.03951	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	0.60%	0.01558	kg 1,4-DCB
CPVC pipes - IN-BR	0.20%	0.00517	kg 1,4-DCB
hydrochloric acid, 30% in H2O, at plant	0.18%	0.00453	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	0.06%	0.00151	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.06%	0.00143	kg 1,4-DCB
Human non-carcinogenic toxicity			
electricity, low voltage, at grid	89.21%	128.90857	kg 1,4-DCB
PVC tanks - IN-BR	2.77%	4.00623	kg 1,4-DCB
anionic resin, at plant	2.45%	3.53965	kg 1,4-DCB
transport, lorry 16-32t,	1.76%	2.53689	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	1.44%	2.0842	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	1.37%	1.97456	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	0.64%	0.92621	kg 1,4-DCB
hydrochloric acid, 30% in H2O, at plant	0.29%	0.41495	kg 1,4-DCB
CPVC pipes - IN-BR	0.07%	0.10442	kg 1,4-DCB
Ionizing radiation			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	37.80%	0.33422	kBq Co-60 eq

Gravel 2/32, production mix, at plant, wet and dry quarry, undried	35.81%	0.31665	kBq Co-60 eq
electricity, low voltage, at grid	24.45%	0.2162	kBq Co-60 eq
anionic resin, at plant	0.79%	0.00697	kBq Co-60 eq
PVC tanks - IN-BR	0.59%	0.00519	kBq Co-60 eq
FRP vessel hand rolled - IN-WB	0.26%	0.00232	kBq Co-60 eq
transport, lorry 16-32t,	0.20%	0.00174	kBq Co-60 eq
hydrochloric acid, 30% in H2O, at plant	0.09%	0.00075	kBq Co-60 eq
CPVC pipes - IN-BR	0.02%	0.00019	kBq Co-60 eq
Land use			
electricity, low voltage, at grid	88.44%	0.00525	m2a crop eq
PVC tanks - IN-BR	5.95%	0.00035	m2a crop eq
transport, lorry 16-32t,	2.24%	0.00013	m2a crop eq
anionic resin, at plant	2.12%	0.00013	m2a crop eq
FRP vessel hand rolled - IN-WB	0.66%	3.93E-05	m2a crop eq
CPVC pipes - IN-BR	0.34%	2.02E-05	m2a crop eq
hydrochloric acid, 30% in H2O, at plant	0.25%	1.47E-05	m2a crop eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.00%	0	m2a crop eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	0.00%	0	m2a crop eq
Marine ecotoxicity			
electricity, low voltage, at grid	88.67%	156.98342	kg 1,4-DCB
PVC tanks - IN-BR	3.06%	5.41026	kg 1,4-DCB
anionic resin, at plant	2.43%	4.30722	kg 1,4-DCB
transport, lorry 16-32t,	1.72%	3.04017	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	1.60%	2.82426	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	1.51%	2.6757	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	0.66%	1.16066	kg 1,4-DCB
hydrochloric acid, 30% in H2O, at plant	0.28%	0.50122	kg 1,4-DCB
CPVC pipes - IN-BR	0.08%	0.13955	kg 1,4-DCB
Marine eutrophication			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	37.13%	3.10E-05	kg N eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	35.18%	2.94E-05	kg N eq
electricity, low voltage, at grid	23.32%	1.95E-05	kg N eq
anionic resin, at plant	3.20%	2.67E-06	kg N eq
PVC tanks - IN-BR	0.67%	5.58E-07	kg N eq
FRP vessel hand rolled - IN-WB	0.25%	2.11E-07	kg N eq
transport, lorry 16-32t,	0.11%	8.98E-08	kg N eq
hydrochloric acid, 30% in H2O, at plant	0.10%	8.09E-08	kg N eq
CPVC pipes - IN-BR	0.05%	3.94E-08	kg N eq
Mineral resource scarcity			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	39.60%	0.00193	kg Cu eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	37.51%	0.00183	kg Cu eq
electricity, low voltage, at grid	18.78%	0.00092	kg Cu eq
anionic resin, at plant	1.87%	9.16E-05	kg Cu eq
transport, lorry 16-32t,	0.98%	4.77E-05	kg Cu eq
PVC tanks - IN-BR	0.53%	2.60E-05	kg Cu eq

FRP vessel hand rolled -	0.50%	2.42E-05	kg Cu eq
hydrochloric acid, 30% in H2O, at plant	0.20%	9.53E-06	kg Cu eq
CPVC pipes - IN-BR	0.04%	1.86E-06	kg Cu eq
Ozone formation, Human health			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	42.81%	0.00353	kg NOx eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	40.55%	0.00335	kg NOx eq
electricity, low voltage, at grid	13.68%	0.00113	kg NOx eq
transport, lorry 16-32t,	1.38%	0.00011	kg NOx eq
PVC tanks - IN-BR	0.87%	7.22E-05	kg NOx eq
anionic resin, at plant	0.46%	3.76E-05	kg NOx eq
FRP vessel hand rolled - IN-WB	0.19%	1.53E-05	kg NOx eq
CPVC pipes - IN-BR	0.05%	3.98E-06	kg NOx eq
hydrochloric acid, 30% in H2O, at plant	0.02%	1.83E-06	kg NOx eq
Ozone formation, Terrestrial ecosystems			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	42.74%	0.00355	kg NOx eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	40.49%	0.00337	kg NOx eq
electricity, low voltage, at grid	13.72%	0.00114	kg NOx eq
transport, lorry 16-32t	1.39%	0.00012	kg NOx eq
PVC tanks - IN-BR	0.91%	7.54E-05	kg NOx eq
anionic resin, at plant	0.47%	3.94E-05	kg NOx eq
FRP vessel hand rolled - IN-WB	0.19%	1.60E-05	kg NOx eq
CPVC pipes - IN-BR	0.05%	4.37E-06	kg NOx eq
hydrochloric acid, 30% in H2O, at plant	0.02%	1.86E-06	kg NOx eq
Stratospheric ozone depletion			
anionic resin, at plant	54.52%	1.66E-06	kg CFC11 eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	11.13%	3.39E-07	kg CFC11 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	10.55%	3.22E-07	kg CFC11 eq
electricity, low voltage, at grid	10.54%	3.21E-07	kg CFC11 eq
PVC tanks - IN-BR	9.12%	2.78E-07	kg CFC11 eq
FRP vessel hand rolled - IN-WB	3.67%	1.12E-07	kg CFC11 eq
transport, lorry 16-32t,	0.39%	1.20E-08	kg CFC11 eq
hydrochloric acid, 30% in H2O, at plant	0.05%	1.54E-09	kg CFC11 eq
CPVC pipes - IN-BR	0.03%	8.09E-10	kg CFC11 eq
Terrestrial acidification			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	41.33%	0.00805	kg SO2 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	39.15%	0.00763	kg SO2 eq
electricity, low voltage, at grid	18.03%	0.00351	kg SO2 eq
PVC tanks - IN-BR	0.73%	0.00014	kg SO2 eq
anionic resin, at plant - CH	0.29%	5.68E-05	kg SO2 eq
transport, lorry 16-32t	0.29%	5.61E-05	kg SO2 eq
FRP vessel hand rolled - IN-WB	0.14%	2.71E-05	kg SO2 eq
Sand 0/2, production mix, at plant, wet and dry quarr	0.02%	4.06E-06	kg SO2 eq
CPVC pipes - IN-BR	0.02%	3.94E-06	kg SO2 eq
Terrestrial ecotoxicity			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	33.77%	0.95856	kg 1,4-DCB

Gravel 2/32, production mix, at plant, wet and dry quarry, undried	32.00%	0.90813	kg 1,4-DCB
electricity, low voltage, at grid - US	29.51%	0.83753	kg 1,4-DCB
transport, lorry 16-32t,	1.85%	0.05248	kg 1,4-DCB
anionic resin, at plant	1.35%	0.03838	kg 1,4-DCB
PVC tanks - IN-BR	0.84%	0.02387	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	0.46%	0.01314	kg 1,4-DCB
hydrochloric acid, 30% in H2O, at plant	0.16%	0.00459	kg 1,4-DCB
CPVC pipes - IN-BR	0.05%	0.00149	kg 1,4-DCB
Water consumption			
electricity, low voltage, at grid	66.55%	2.27053	m3
anionic resin, at plant	1.81%	0.0618	m3
PVC tanks - IN-BR	1.14%	0.03874	m3
transport, lorry 16-32t,	0.51%	0.01744	m3
FRP vessel hand rolled - IN-WB	0.49%	0.01663	m3
hydrochloric acid, 30% in H2O, at plant	0.18%	0.0063	m3
CPVC pipes - IN-BR	0.05%	0.00176	m3
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	-0.14%	-0.0048	m3
Sand 0/2, production mix, at plant, wet and dry quarry, undried	-0.15%	-0.00507	m3

Process flow contributions to impact categories Activated Alumina Plant Khairapatti

Process	contribution	Amount	Unit
Fine particulate matter formation			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	47.45%	0.00151	kg PM2.5 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	44.95%	0.00143	kg PM2.5 eq
activated carbon, granular	2.76%	8.79E-05	kg PM2.5 eq
electricity, production mix photovoltaic, at plant	1.91%	6.09E-05	kg PM2.5 eq
PVC tanks - IN-BR	0.90%	2.88E-05	kg PM2.5 eq
aluminium oxide, at plant	0.83%	2.64E-05	kg PM2.5 eq
transport, lorry 16-32t,	0.68%	2.16E-05	kg PM2.5 eq
FRP vessel hand rolled - IN-WB	0.46%	1.46E-05	kg PM2.5 eq
CPVC pipes - IN-BR	0.05%	1.64E-06	kg PM2.5 eq
Fossil resource scarcity			
activated carbon, granular |	26.96%	0.01196	kg oil eq
electricity, production mix photovoltaic, at plant	26.60%	0.0118	kg oil eq
transport, lorry 16-32t	12.58%	0.00558	kg oil eq

aluminium oxide, at plant	11.58%	0.00514	kg oil eq
PVC tanks - IN-BR	10.78%	0.00478	kg oil eq
FRP vessel hand rolled - IN-WB	9.39%	0.00417	kg oil eq
CPVC pipes - IN-BR	2.10%	0.00093	kg oil eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.00%	0	kg oil eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	0.00%	0	kg oil eq
Freshwater ecotoxicity			
electricity, production mix photovoltaic, at plant	60.06%	0.00428	kg 1,4-DCB
aluminium oxide, at plant	14.43%	0.00103	kg 1,4-DCB
activated carbon, granular |	10.70%	0.00076	kg 1,4-DCB
PVC tanks - IN-BR	5.88%	0.00042	kg 1,4-DCB
transport, lorry 16-32t	3.35%	0.00024	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	2.38%	0.00017	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	1.50%	0.00011	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	1.42%	0.0001	kg 1,4-DCB
CPVC pipes - IN-BR	0.29%	2.04E-05	kg 1,4-DCB
Freshwater eutrophication			
electricity, production mix photovoltaic, at plant	44.77%	3.56E-05	kg P eq
activated carbon, granular	25.45%	2.03E-05	kg P eq
aluminium oxide, at plant - RER	8.39%	6.68E-06	kg P eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried - RER	5.13%	4.08E-06	kg P eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	4.86%	3.87E-06	kg P eq
PVC tanks - IN-BR	4.77%	3.80E-06	kg P eq
FRP vessel hand rolled - IN-WB	4.55%	3.62E-06	kg P eq
transport, lorry 16-32t,	1.73%	1.37E-06	kg P eq
CPVC pipes - IN-BR	0.34%	2.71E-07	kg P eq
Global warming			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	47.79%	0.98902	kg CO2 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	45.28%	0.93699	kg CO2 eq
market for activated carbon, granular | activated carbon, granular |	2.04%	0.04226	kg CO2 eq
electricity, production mix photovoltaic, at plant	1.99%	0.04122	kg CO2 eq
aluminium oxide, at plant	0.80%	0.01646	kg CO2 eq
transport, lorry 16-32t,	0.77%	0.01603	kg CO2 eq
PVC tanks - IN-BR	0.71%	0.01477	kg CO2 eq
FRP vessel hand rolled - IN-WB	0.53%	0.01093	kg CO2 eq
CPVC pipes - IN-BR	0.09%	0.00186	kg CO2 eq
Human carcinogenic toxicity			
aluminium oxide, at plant	62.08%	1.03586	kg 1,4-DCB
electricity, production mix photovoltaic, at plant	17.69%	0.29514	kg 1,4-DCB
PVC tanks - IN-BR	9.36%	0.15616	kg 1,4-DCB
activated carbon, granular	6.32%	0.10541	kg 1,4-DCB
transport, lorry 16-32t	2.54%	0.04242	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	1.51%	0.02522	kg 1,4-DCB

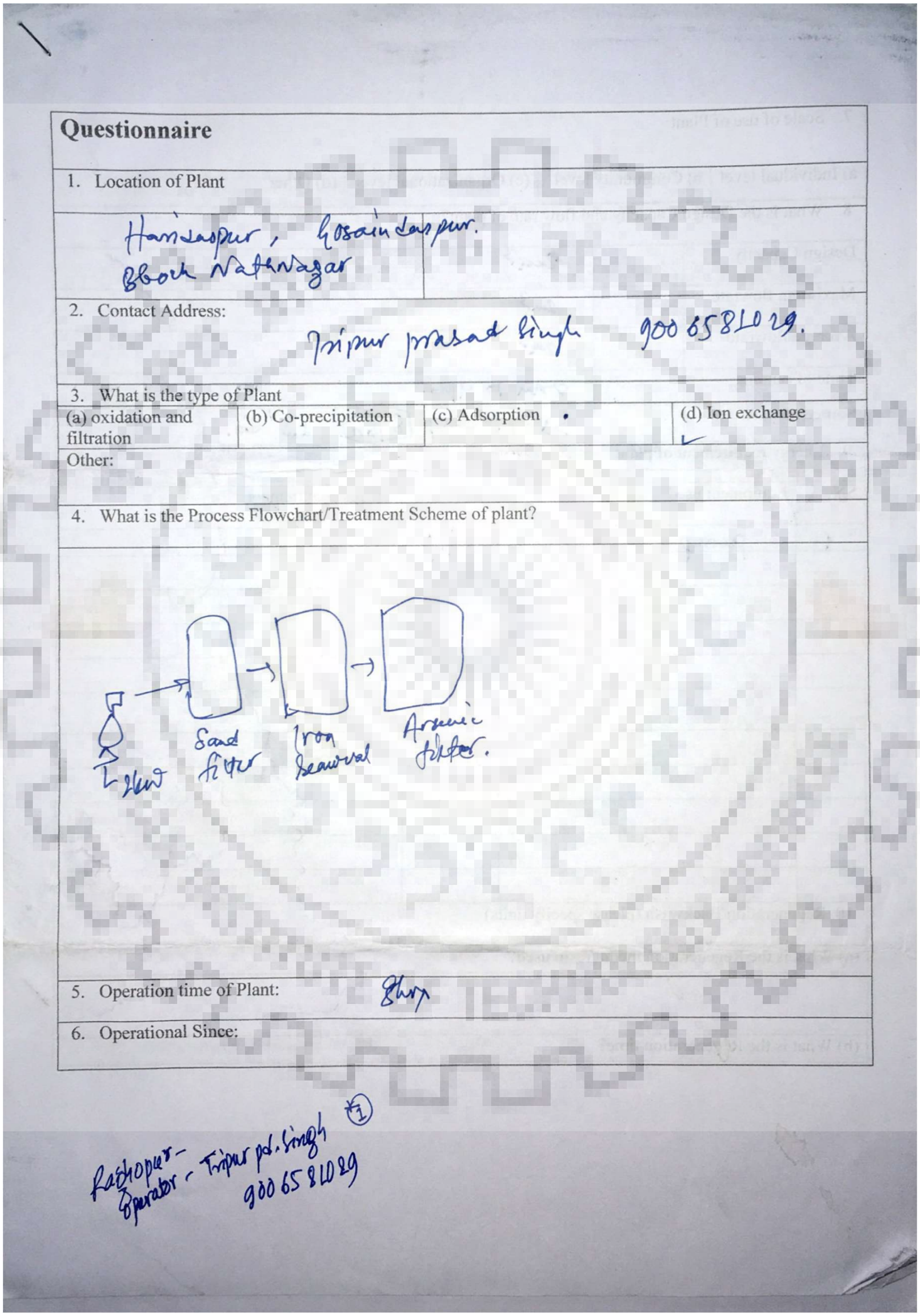
CPVC pipes - IN-BR	0.39%	0.00643	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	0.06%	0.00097	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.05%	0.00092	kg 1,4-DCB
Human non-carcinogenic toxicity			
electricity, production mix photovoltaic, at plant	70.74%	41.36751	kg 1,4-DCB
activated carbon, granular	10.88%	6.35997	kg 1,4-DCB
transport, lorry 16-32t	4.66%	2.72354	kg 1,4-DCB
PVC tanks - IN-BR	3.54%	2.06785	kg 1,4-DCB
aluminium oxide, at plant	2.96%	1.7326	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	2.56%	1.49933	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry,	2.28%	1.33394	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry	2.16%	1.26377	kg 1,4-DCB
CPVC pipes - IN-BR	0.22%	0.12985	kg 1,4-DCB
Ionizing radiation			
Sand 0/2, production mix, at plant, wet and dry quarry,	47.77%	0.21391	kBq Co-60 eq
Gravel 2/32, production mix, at plant, wet and dry quarry,	45.26%	0.20266	kBq Co-60 eq
electricity, production mix photovoltaic, at plant	3.68%	0.01648	kBq Co-60 eq
FRP vessel hand rolled - IN-WB	0.84%	0.00376	kBq Co-60 eq
aluminium oxide, at plant	0.75%	0.00338	kBq Co-60 eq
activated carbon, granular |	0.63%	0.00283	kBq Co-60 eq
PVC tanks - IN-BR	0.60%	0.00268	kBq Co-60 eq
transport, lorry 16-32t	0.42%	0.00187	kBq Co-60 eq
CPVC pipes - IN-BR	0.05%	0.00023	kBq Co-60 eq
Land use			
electricity, production mix photovoltaic, at plant	41.86%	0.00054	m2a crop eq
activated carbon, granular |	18.57%	0.00024	m2a crop eq
PVC tanks - IN-BR	14.13%	0.00018	m2a crop eq
transport, lorry 16-32t	11.06%	0.00014	m2a crop eq
aluminium oxide, at plant	7.50%	9.68E-05	m2a crop eq
FRP vessel hand rolled - IN-WB	4.93%	6.36E-05	m2a crop eq
CPVC pipes - IN-BR	1.95%	2.51E-05	m2a crop eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	0.00%	0	m2a crop eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	0.00%	0	m2a crop eq
Marine ecotoxicity			
electricity, production mix photovoltaic, at plant	66.33%	50.21214	kg 1,4-DCB
| activated carbon, granular |	10.32%	7.81372	kg 1,4-DCB
aluminium oxide, at plant	7.98%	6.04091	kg 1,4-DCB
transport, lorry 16-32t,	4.31%	3.26385	kg 1,4-DCB
PVC tanks - IN-BR	3.69%	2.79255	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	2.48%	1.87885	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	2.39%	1.8076	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	2.26%	1.71252	kg 1,4-DCB
CPVC pipes - IN-BR	0.23%	0.17353	kg 1,4-DCB
Marine eutrophication			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	44.54%	1.98E-05	kg N eq

Gravel 2/32, production mix, at plant, wet and dry quarry, undried	42.20%	1.88E-05	kg N eq
electricity, production mix photovoltaic, at plant	8.06%	3.59E-06	kg N eq
activated carbon, granular |	2.91%	1.30E-06	kg N eq
FRP vessel hand rolled - IN-WB	0.77%	3.41E-07	kg N eq
PVC tanks - IN-BR	0.65%	2.88E-07	kg N eq
aluminium oxide, at plant	0.55%	2.46E-07	kg N eq
transport, lorry 16-32t	0.22%	9.64E-08	kg N eq
CPVC pipes - IN-BR	0.11%	4.91E-08	kg N eq
Mineral resource scarcity			
aluminium oxide, at plant	28.94%	0.00141	kg Cu eq
Sand 0/2, production mix, at plant, wet and dry quarry, undried	25.36%	0.00124	kg Cu eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	24.03%	0.00117	kg Cu eq
electricity, production mix photovoltaic, at plant	19.15%	0.00094	kg Cu eq
transport, lorry 16-32t,	1.05%	5.12E-05	kg Cu eq
FRP vessel hand rolled - IN-WB	0.80%	3.92E-05	kg Cu eq
activated carbon, granular |	0.35%	1.70E-05	kg Cu eq
PVC tanks - IN-BR	0.28%	1.34E-05	kg Cu eq
CPVC pipes - IN-BR	0.05%	2.31E-06	kg Cu eq
Ozone formation, Human health			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	46.62%	0.00226	kg NOx eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	44.16%	0.00214	kg NOx eq
transport, lorry 16-32t	2.51%	0.00012	kg NOx eq
activated carbon, granular |	2.23%	0.00011	kg NOx eq
electricity, production mix photovoltaic, at plant	2.00%	9.72E-05	kg NOx eq
aluminium oxide, at plant	1.09%	5.31E-05	kg NOx eq
PVC tanks - IN-BR	0.77%	3.72E-05	kg NOx eq
FRP vessel hand rolled - IN-WB	0.51%	2.47E-05	kg NOx eq
CPVC pipes - IN-BR	0.10%	4.94E-06	kg NOx eq
Ozone formation, Terrestrial ecosystems			
Sand 0/2, production mix, at plant, wet and dry quarry	46.52%	0.00227	kg NOx eq
Gravel 2/32, production mix, at plant, wet and dry quarry,	44.07%	0.00215	kg NOx eq
transport, lorry 16-32t	2.54%	0.00012	kg NOx eq
activated carbon, granular |	2.23%	0.00011	kg NOx eq
electricity, production mix photovoltaic, at plant	2.10%	0.0001	kg NOx eq
aluminium oxide, at plant	1.11%	5.42E-05	kg NOx eq
PVC tanks - IN-BR	0.80%	3.89E-05	kg NOx eq
FRP vessel hand rolled - IN-WB	0.53%	2.59E-05	kg NOx eq
CPVC pipes - IN-BR	0.11%	5.43E-06	kg NOx eq
Stratospheric ozone depletion			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	26.51%	2.17E-07	kg CFC11 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	25.12%	2.06E-07	kg CFC11 eq
FRP vessel hand rolled - IN-WB	22.09%	1.81E-07	kg CFC11 eq
PVC tanks - IN-BR	17.52%	1.44E-07	kg CFC11 eq
electricity, production mix photovoltaic, at plant	4.16%	3.41E-08	kg CFC11 eq
activated carbon, granular |	2.02%	1.65E-08	kg CFC11 eq

transport, lorry 16-32t, EURO3 - RER	1.58%	1.29E-08	kg CFC11 eq
aluminium oxide, at plant - RER	0.89%	7.27E-09	kg CFC11 eq
CPVC pipes - IN-BR	0.12%	1.01E-09	kg CFC11 eq
Terrestrial acidification			
Sand 0/2, production mix, at plant, wet and dry quarry, undried	48.26%	0.00515	kg SO2 eq
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	45.73%	0.00488	kg SO2 eq
activated carbon, granular |	2.13%	0.00023	kg SO2 eq
electricity, production mix photovoltaic, at plant - US	1.55%	0.00017	kg SO2 eq
PVC tanks - IN-BR	0.69%	7.39E-05	kg SO2 eq
aluminium oxide, at plant - RER	0.62%	6.58E-05	kg SO2 eq
transport, lorry 16-32t,	0.56%	6.02E-05	kg SO2 eq
FRP vessel hand rolled - IN-WB	0.41%	4.39E-05	kg SO2 eq
CPVC pipes - IN-BR	0.05%	4.90E-06	kg SO2 eq
Terrestrial ecotoxicity			
electricity, production mix photovoltaic, at plant	47.60%	1.31453	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	22.22%	0.6135	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	21.05%	0.58122	kg 1,4-DCB
aluminium oxide, at plant	4.44%	0.12253	kg 1,4-DCB
transport, lorry 16-32t,	2.04%	0.05634	kg 1,4-DCB
| activated carbon, granular |	1.37%	0.03779	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	0.77%	0.02127	kg 1,4-DCB
PVC tanks - IN-BR	0.45%	0.01232	kg 1,4-DCB
CPVC pipes - IN-BR	0.07%	0.00186	kg 1,4-DCB
Water consumption			
electricity, production mix photovoltaic, at plant -	47.60%	1.31453	kg 1,4-DCB
Sand 0/2, production mix, at plant, wet and dry quarry, undried	22.22%	0.6135	kg 1,4-DCB
Gravel 2/32, production mix, at plant, wet and dry quarry, undried	21.05%	0.58122	kg 1,4-DCB
aluminium oxide, at plant	4.44%	0.12253	kg 1,4-DCB
transport, lorry 16-32t,	2.04%	0.05634	kg 1,4-DCB
activated carbon, granular |	1.37%	0.03779	kg 1,4-DCB
FRP vessel hand rolled - IN-WB	0.77%	0.02127	kg 1,4-DCB
PVC tanks - IN-BR	0.45%	0.01232	kg 1,4-DCB
CPVC pipes - IN-BR	0.07%	0.00186	kg 1,4-DCB

Appendix I

Data collection from Questionnaire (Haridashpur, Nathnagar, Bhagalpur)



Questionnaire

1. Location of Plant	
Harisaspur, Gosaindaspur. Block Nathnagar	
2. Contact Address: Tripur prasad Singh 9006581029.	

3. What is the type of Plant

(a) oxidation and filtration	(b) Co-precipitation	(c) Adsorption	(d) Ion exchange ✓

Other:

4. What is the Process Flowchart/Treatment Scheme of plant?

5. Operation time of Plant: 8hrs

6. Operational Since:

Rashopur - Operator - Tripur pd. Singh 9006581029

7. Scale of use of Plant:			
a) Individual level	b) Community level	(c) Organizational level	(d) Other

8. What is the Design Capacity and flow rate of plant?

Design Capacity		2m3
Maximum flowrate		2m3
Average flowrate		2m3.
Time of running		8 Am to 4pm.
Source of water		350ft deep [8 inch Bore] 1.5" dia.

9. Energy requirement of plant

SN	Equipment used	Unit	Energy requirement
1.	pump	2 Hp	

10. Regeneration/Backwash (please specify units)

(a) What is the Regeneration media/resin used?

(b) What is the Regeneration time?

(c) What is the Regeneration flow rate?
(d) What is the Quantity of regeneration media/resin used per regeneration cycle? What is the Solution Concentration (mass/mass)?
—
(e) What is the Backwash Time?
8hrs.
(f) What is the Backwash flow rate?
1 m3/h
(g) What is the Output between regeneration?
—

11. Monitoring of the plant

(i)Water Parameters Measured

(a)Arsenic	(e)Total Nitrite	(i)Chloride	(m)Silica
(b)Arsenate [As (V)]	(f)pH	(j)Fluoride	(n)Sulfate
(c)Arsenite [As (III)]	(g)Iron	(k)Manganese	(o)Nitrate
(d)Orthophosphate	(h)Total Dissolved Solids (TDS)	(l)Total Organic Carbon (TOC)	

(ii)Frequency of water quality monitoring

once in 3 months

(iii)Lab Analysis and Lab facilities at site N.A.

12. Maintenance periodic (6 months)			
(i)Type of maintenance Scheme:			
(ii)What is the breakdown time and frequency of breakdown?			
(ii)Skill level required for operation and maintenance			
(a) Unskilled	✓(b) Semi Skilled	(c) Skilled	(d) highly skilled
(iii)Number of workers			
(a) Unskilled	(b) Semi Skilled (1)	(c) Skilled	(d) highly skilled
13. Infrastructure Requirements			
(i)Power:	N.A.		
(ii)Water:	(60ft x 80ft)		
(iii)Other:			
14. What is Land Area occupied by the plant?			
60ft x 50ft			
15. What are the Construction/Installation Costs?			

16. What are the Maintenance Costs?

17. Pre/post treatment

(a)Is pre-oxidation of Arsenite to Arsenate required? Associated costs?

—

(b)Is pH adjustment required? Associated costs?

—

(c)Is pre-filtration required? Associated costs?

—

18. Operation Costs? (Materials, Labor, Energy)

—

19. What is the quantity of hazardous waste sludge/ material is produced? What is the method of its disposal? How and where it is transported?

disposed at site only

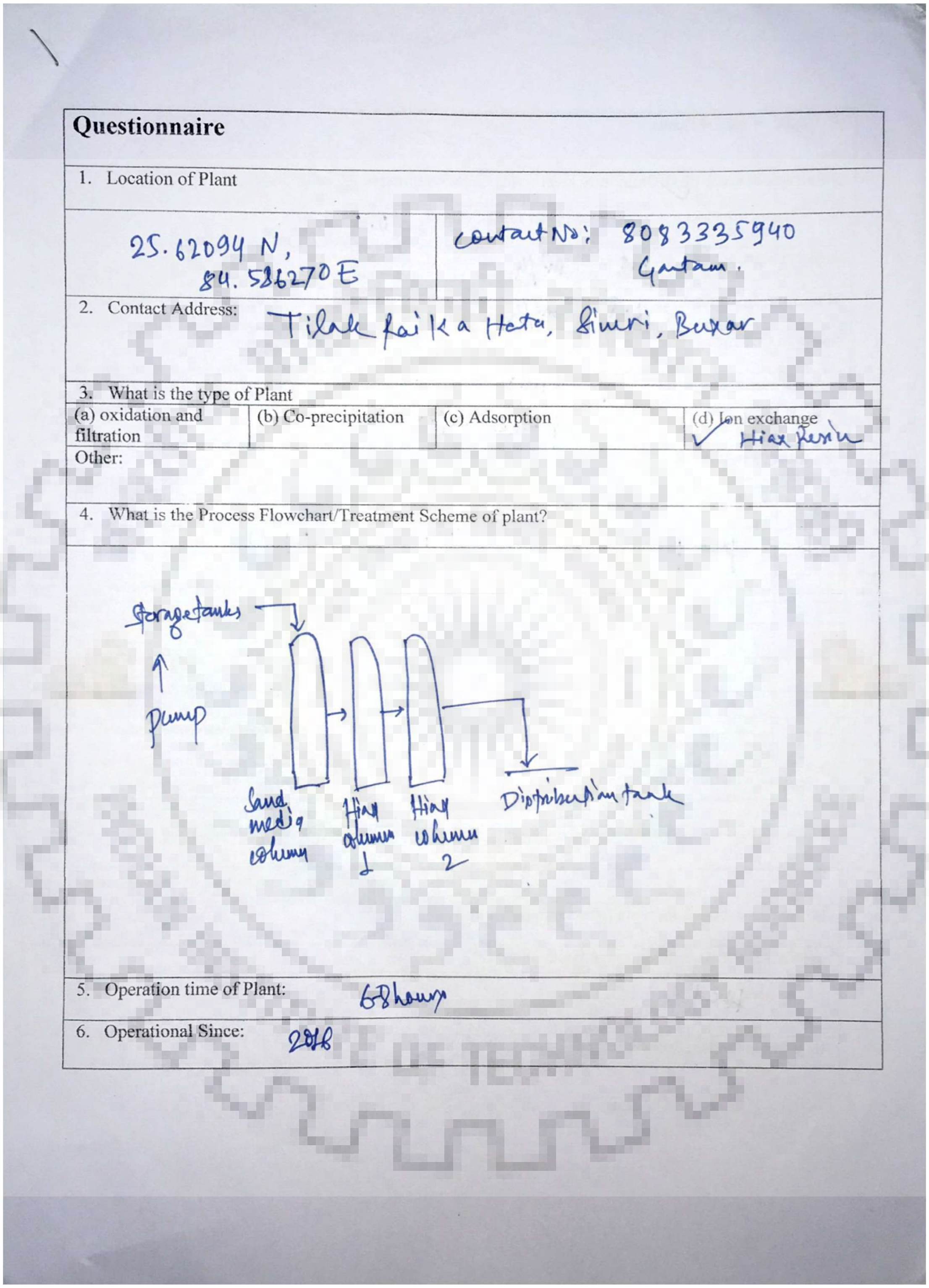
20. What are the potential environmental impacts from the treatment process?

—

21. Can the quantities and hazard level of residuals be minimized?
Yes. through proper disposal of spent media
22. Do the public understand and trust the reliability and safety of the technology?
Yes.
23. Are locals satisfied with the setup?
Yes.
24. Does the influent water quality vary?
No.
25. Can the treatment system handle these variations?
—
26. What is the Distribution Scheme of plant?
Distribution through pipeline.
27. What is the number of People served by the plant? Does the number vary (If yes reasons)?
110 house holds 1000 people
28. Can the plant be upgraded to a newer Technology?
—

110 house holds
1000 people.

Data collection from questionnaire Tilak Rai Ka Hata, Simri, Buxar



Questionnaire

1. Location of Plant

25.62094 N, 84.586270 E	contact No: 8083335940 Gautam.

2. Contact Address: Tilak Rai Ka Hata, Simri, Buxar

3. What is the type of Plant

(a) oxidation and filtration	(b) Co-precipitation	(c) Adsorption	(d) Ion exchange ✓ Hiax Resin

Other:

4. What is the Process Flowchart/Treatment Scheme of plant?

5. Operation time of Plant: 6-8 hours

6. Operational Since: 2016

7. Scale of use of Plant:			
a) Individual level	b) Community level ✓	(c) Organizational level	(d) Other

8. What is the Design Capacity and flow rate of plant? 0.

Design Capacity	0.8	m^3/h
Maximum flowrate	0.8	m^3/h
Average flowrate		
Time of running	6	hours
Source of water		ground water

9. Energy requirement of plant

SN	Equipment used	Unit	Energy requirement
1.	pump	HP	1119 W

10. Regeneration/Backwash (please specify units)

(a) What is the Regeneration media/resin used?

HCl

(b) What is the Regeneration time?

30 mins to 1 hr.
(c) What is the Regeneration flow rate?
0.4 m^3/h
(d) What is the Quantity of regeneration media/resin used per regeneration cycle? What is the Solution Concentration (mass/mass)?
–
(e) What is the Backwash Time?
15-30 mins
(f) What is the Backwash flow rate?
0.4 m^3/h
(g) What is the Output between regeneration?
16000 BV regeneration

11. Monitoring of the plant

(i) Water Parameters Measured N.A.

(a)Arsenic	(e)Total Nitrite	(i)Chloride	(m)Silica
(b)Arsenate [As (V)]	(f)pH	(j)Fluoride	(n)Sulfate
(c)Arsenite [As (III)]	(g)Iron	(k)Manganese	(o)Nitrate
(d)Orthophosphate	(h)Total Dissolved Solids (TDS)	(l)Total Organic Carbon (TOC)	

(ii) Frequency of water quality monitoring

3-6 months

(iii) Lab Analysis and Lab facilities at site None

—

12. Maintenance Scheduled 1-2 months

(i)Type of maintenance Scheme:

Scheduled

(ii)What is the breakdown time and frequency of breakdown?

None

(ii)Skill level required for operation and maintenance

(a) Unskilled ✓	(b) Semi Skilled ✓	(c) Skilled	(d) highly skilled

(iii)Number of workers 1

(a) Unskilled 1	(b) Semi Skilled	(c) Skilled	(d) highly skilled

13. Infrastructure Requirements

(i)Power:	1119 kW
(ii)Water:	
(iii)Other:	

14. What is Land Area occupied by the plant?

20 ft. x 15 ft.

15. What are the Construction/Installation Costs?

5.5 lakhs.

16. What are the Maintenance Costs?

—

17. Pre/post treatment

(a)Is pre-oxidation of Arsenite to Arsenate required? Associated costs?

—

(b)Is pH adjustment required? Associated costs?

—

(c)Is pre-filtration required? Associated costs?

—

18. Operation Costs? (Materials, Labor, Energy)

free electricity

19. What is the quantity of hazardous waste sludge/ material is produced? What is the method of its disposal? How and where it is transported?

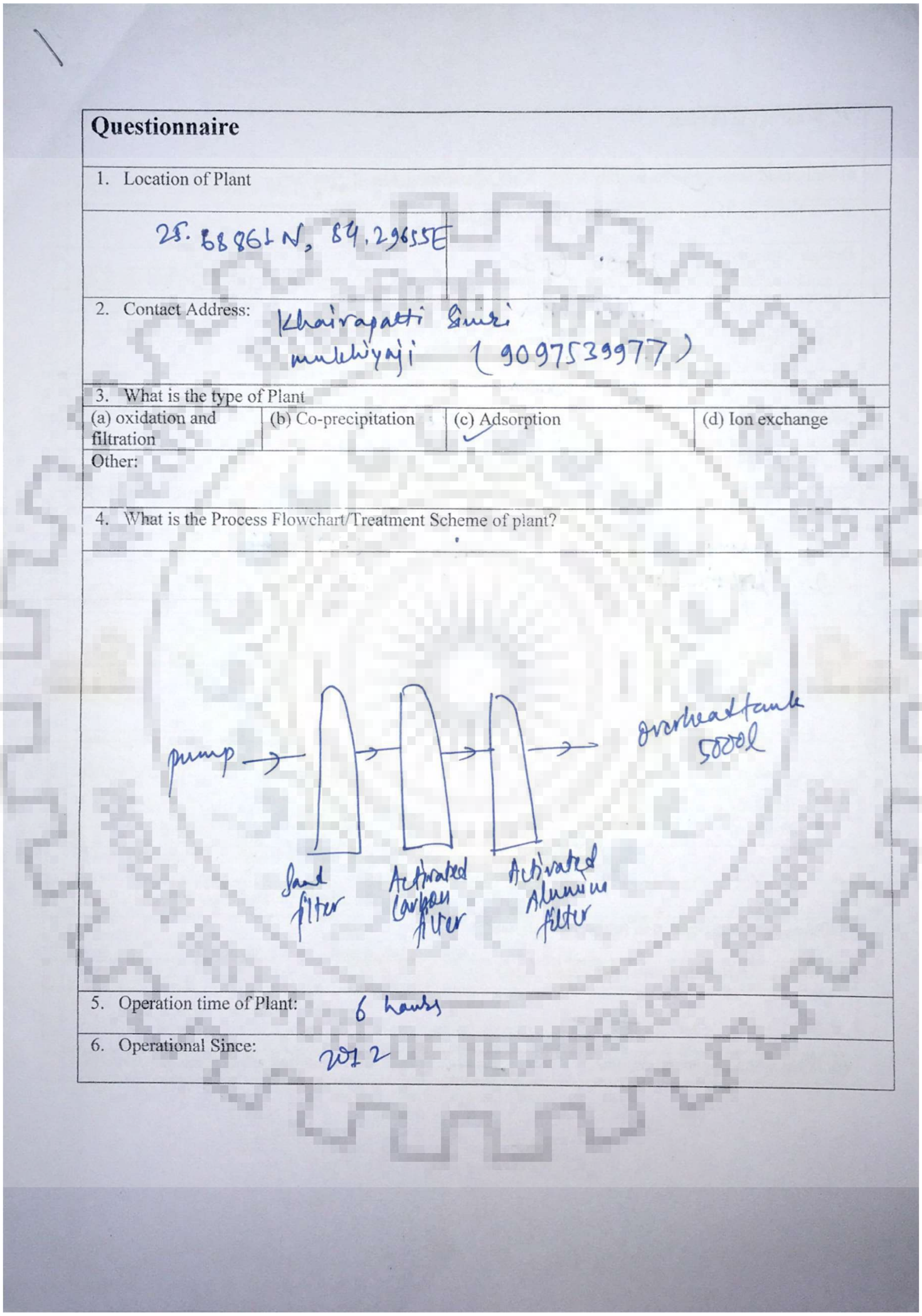
disposal of brine and backwash water to backwash pit.

20. What are the potential environmental impacts from the treatment process?

—

21. Can the quantities and hazard level of residuals be minimized?
—
22. Do the public understand and trust the reliability and safety of the technology?
yes.
23. Are locals satisfied with the setup?
yes.
24. Does the influent water quality vary?
—
25. Can the treatment system handle these variations?
—
26. What is the Distribution Scheme of plant?
containers to be filled at plant site
27. What is the number of People served by the plant? Does the number vary (If yes reasons)?
30 households, sometimes the number vary
28. Can the plant be upgraded to a newer Technology?
NO. consolidated plant.

Data collection from questionnaire Khairapatti, Simri, Buxar



Questionnaire

1. Location of Plant			
25.88861 N, 84.29655E			
2. Contact Address: Khairapatti Simri mukhiyaji (9097539977)			
3. What is the type of Plant			
(a) oxidation and filtration	(b) Co-precipitation	(c) Adsorption ✓	(d) Ion exchange
Other:			
4. What is the Process Flowchart/Treatment Scheme of plant?			
pump → Sand filter → Activated Carbon filter → Activated Alumina filter → overhead tank 5000l			
5. Operation time of Plant: 6 hours			
6. Operational Since: 2012			

7. Scale of use of Plant:			
a) Individual level	b) Community level ✓	(c) Organizational level	(d) Other

8. What is the Design Capacity and flow rate of plant?

Design Capacity	10000	lpd
Maximum flowrate	1.1666	m^3/h
Average flowrate	1.2	m^3/h
Time of running	6	hours
Source of water		Groundwater

9. Energy requirement of plant

SN	Equipment used	Unit	Energy requirement
1.	pump	KW	1.492 kw
2.	light bulbs	W	100

10. Regeneration/Backwash (please specify units)

(a) What is the Regeneration media/resin used?

—

(b) What is the Regeneration time? —

(c) What is the Regeneration flow rate?
—— .
(d) What is the Quantity of regeneration media/resin used per regeneration cycle? What is the Solution Concentration (mass/mass)?
——
(e) What is the Backwash Time?
30 mins every 24 hours of operation
(f) What is the Backwash flow rate?
1 m^3/h.
(g) What is the Output between regeneration?
18-22 months media changed

11. Monitoring of the plant

(i)Water Parameters Measured

(a)Arsenic	(e)Total Nitrite	(i)Chloride	(m)Silica
(b)Arsenate [As (V)]	(f)pH	(j)Fluoride	(n)Sulfate
(c)Arsenite [As (III)]	(g)Iron	(k)Manganese	(o)Nitrate
(d)Orthophosphate	(h)Total Dissolved Solids (TDS)	(l)Total Organic Carbon (TOC)	

(ii)Frequency of water quality monitoring

1-2 months by PHED.

(iii)Lab Analysis and Lab facilities at site ——

Samples sent to PHED lab Buxar

12. Maintenance

(i)Type of maintenance Scheme:

maintenance by 3rd party contractor of PHED visit once every month

(ii)What is the breakdown time and frequency of breakdown?

—

(ii)Skill level required for operation and maintenance

(a) Unskilled ✓	(b) Semi Skilled	(c) Skilled	(d) highly skilled

(iii)Number of workers 1

(a) Unskilled ✓	(b) Semi Skilled	(c) Skilled	(d) highly skilled

13. Infrastructure Requirements

(i)Power:	
(ii)Water:	
(iii)Other:	

14. What is Land Area occupied by the plant?

85 ft x 65 ft.

15. What are the Construction/Installation Costs?

45,68,000

16. What are the Maintenance Costs?
—
17. Pre/post treatment
(a)Is pre-oxidation of Arsenite to Arsenate required? Associated costs?
—
(b)Is pH adjustment required? Associated costs?
—
(c)Is pre-filtration required? Associated costs?
—
18. Operation Costs? (Materials, Labor, Energy)
3000/month salary of operator
19. What is the quantity of hazardous waste sludge/ material is produced? What is the method of its disposal? How and where it is transported?
Backwash water to sump.
20. What are the potential environmental impacts from the treatment process?
—

21. Can the quantities and hazard level of residuals be minimized?

— Disposal of residue / media at site only

22. Do the public understand and trust the reliability and safety of the technology?

~~Yes~~ - but no knowledge about the technology & safety

23. Are locals satisfied with the setup?

Yes

24. Does the influent water quality vary?

—

25. Can the treatment system handle these variations?

—

26. What is the Distribution Scheme of plant?

distribution through gravity flow tank to piped water scheme 15 supply taps.

27. What is the number of People served by the plant? Does the number vary (If yes reasons)?

150 households, No. vary sometimes

28. Can the plant be upgraded to a newer Technology?

No.