CHAPTER 6

LIFE CYCLE ASSESSMENT OF GROUNDWATER SUPPLY SYSTEM IN A HYPER-ARID REGION OF INDIA

6.1 INTRODUCTION

Water is one of the most important resources for sustaining all forms of life by fulfilling basic needs and health. The demand for freshwater use to meet the daily needs grew twice as fast as the world's population. The major thrust behind this was 70% of global water withdrawal for agricultural purposes (Berger et al., 2016; Finkbeiner, 2016). The over exploitation of freshwater bodies including groundwater may create a situation of freshwater crisis for future generations especially in Asia and Africa (Koehler, 2008). In many regions of India, the groundwater replenishment is dependent upon rainfall. It is observed that in the last decades the rainfall is scanty and not sufficient to replenish the levels of groundwater extracted during non-monsoonal times (Srinivas et al., 2015). The second important aspect of ground water is its extraction, which is mainly done using electricity. According to Gilron (2014), the connection between energy and water is quite complicated, as generation of electricity also demands for high water consumption (Gilron, 2014). In Indian context, 59.9% of the total electricity is generated using coal based thermal power plants (CEA India, 2014). This makes the situation of water energy nexus more complicated for extraction of ground water in the hyper arid regions of India, where ground water is the only source of freshwater and energy is generated using coal based power plants. The environmental impacts associated with the consumption of water are often neglected, especially with regard to agricultural production that happens in water scarce areas (Berger et al., 2016; Finkbeiner, 2016). Hence, management of water resources in the arid and hyper arid zones is essential.

Life Cycle Assessment (LCA) is a commonly used environmental management tool for assessing environmental consequences throughout the product life cycle. However, in the existing research for LCA of products or processes, attention is provided only for pollution of freshwater resources by various categories. The tool of LCA is mainly emerged in developed economies and availability of freshwater varies at various locations around the globe, which makes it challenging for the impact assessment of water use with different water qualities (Finkbeiner, 2016). In case of arid countries (for example India, Australia, Spain) and water intensive crops, impact of water used can be the main contributor to overall food production impacts (Dijkman and Basset-mens, 2018).

The current study aims to visualize the potential environmental impacts of groundwater supply system for irrigation purpose using LCA. The study area (i.e. Bikaner block) under consideration falls under hyper arid zone category in the Thar Desert of India. In this region, most of the irrigation systems rely on groundwater supply, which is extracted from deep bored tube wells using submersible pumping system. In this study, environmental impact assessment of groundwater extraction from tube wells and its use for agricultural purpose has been performed. The system boundary of the study consists of well construction (WC), groundwater extraction (GWE), distribution (D), and end-of-life (EoL). The data for the study has been collected through semi-structured interviews conducted with the farmers, equipment dealers, and authorities of district electricity board. The actual measurement of material and energy consumption have also been done to validate the data.

6.2 LCA AND WATER RESOURCE MANAGEMENT

The boundary of LCA begins with raw material extraction and ends when all materials are returned to the earth. LCA is a tool used for qualitative and quantitative assessment of environmental hazards and life cycle costing of product, process or value chain (Klöpffer, 1997).

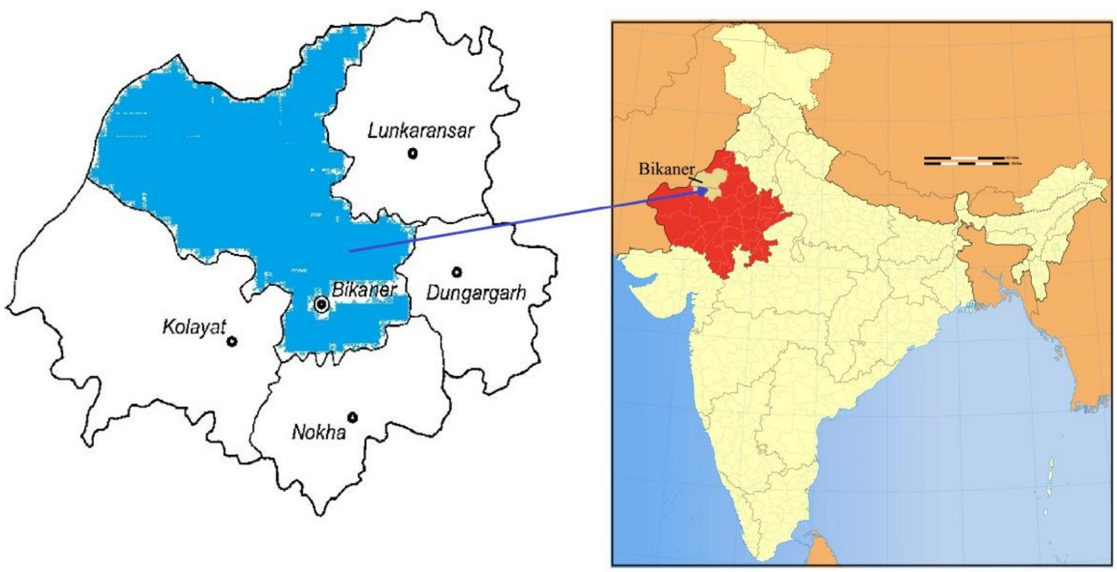


Figure 6.1. Map showing location Bikaner district and five blocks of the district

LCA has been widely used nowadays for various products and processes (Bhakar et al., 2015), but this is yet not popular in the field of freshwater resource management, especially in India. Many researchers around the world have focused on application of life cycle management tools to assess freshwater resources and their overall impact upon environment, socio-economic aspects, and vice versa. Koehler (2008) highlighted the critical aspects of water use in LCA and also pointed out the issue of water scarcity in Asia, particularly in India and China. According to Bayer et al. (2009), LCA of groundwater extraction is a potential research topic.

It stated that LCA as a tool needs further consideration beyond its industrial applications. Boulay et al. (2011) focused on categorizing the type of water and water users for LCA inventory. The study categorized two types of agricultural water users: one is good quality irrigation water user and another is relatively poor-quality water user. Milà et al. (2009) focused on assessment of freshwater use impacts, development of inventory model, and characterization factors for impact assessment. A few studies have applied LCA in agricultural sector. Birkved and Hauschild (2006) used LCA to estimate the environmental impacts due to use of pesticide in agricultural and illustrated the capability of the model through two real time Danish case studies. Dijkman et al. (2012) also focused on impacts related to use of pesticides in agricultural sector in Europe. In this sequence, few studies have been conducted in the context of water footprint assessments in India. Bhakar et al. (2015) focused on assessing the environmental impacts associated with water supply system of a university campus. Another study by Bhakar et al. (2016) focused on treatment and purification of freshwater supplied to the residents of a university campus for drinking purposes. Ghazi et al. (2008) evaluated the environmental impacts associated with the mud generated in drilling operations.

6.3 GEOGRAPHICAL LOCATION OF THE STUDY AREA

Bikaner is located in the north-western part of the state of Rajasthan and has international border with Pakistan. It has an area of 30381.75 sq. km. It lies between 27° 11’ and 29° 03’ north latitudes and 71° 54’ and 74° 12’ east longitudes. The district is having five blocks/panchayat samities viz. Bikaner, Kolayat, Lunkaransar, Sri Dungargarh, and Nokha. The location of study area is shown in Figure 6.1. The climate of the Bikaner block ranges from arid in the east to extremely arid/hyper arid in the west and is characterized by large extremes of temperature, erratic rainfall and high evaporation. Being situated on the western side of Aravalli hill ranges, the area is characterized as typical rain shadow region resulting in low precipitation. The average annual rainfall of the block is 262.11 mm for the last eleven decades. High temperature here starts from April onwards whereas May and June are the hottest months of the year. From April to June, temperature exceeds 40.0°C generally whereas in some years' temperature has been recorded above 47.0°C. With the onset of monsoon in late June or early July, the daytime temperature falls to 38.0°C in July to 36.0°C in August and September.

6.4 MATERIALS AND METHODS

In this study, environmental impacts associated with one kilolitre of groundwater extracted for agricultural purposes have been assessed using LCA. The LCA is carried out using ISO 14040 framework (ISO, 1997). This framework consists of four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO, 1997). This study utilizes a cradle to grave approach to model the material and energy flows. The life cycle environmental impact assessment of ground water extraction can visualize the hotspots and might be helpful in decision making for groundwater extraction. In this study, Umberto NXT Universal software and Ecoinvent dataset version 3.0 (Swiss Centre for Life Cycle Inventories, 2015) are used to model the energy and material flow. The well-known ReCiPe impact assessment method is utilized for both endpoint and midpoint assessment. The impacts generated due to extraction of one kilolitre of groundwater are plotted against various impact categories and interpretations have been drawn based on potential impact assessed corresponding to each category.

6.5 GOAL AND SCOPE DEFINITION

6.5.1 Functional Unit

In the present study, the functional unit has been considered as one cubic meter of groundwater (freshwater) distributed for irrigation purposes from a tube well using submersible pump.

6.5.2 System Boundary

The system boundary of the study includes the construction of tube wells (including rotary drilling operation, pipe lowering, gravel packing, and submersible pump installation), groundwater extraction, distribution using sprinkler system, and disposal of the material after useful life. The system boundary of the study has been shown in Figure 6.2.

6.5.3 Inventory Analysis

The inventory analysis of the study has been carried out using both primary and secondary data. For primary data collection, semi structured interviews were conducted among various stakeholders dealing with various aspects of groundwater management. The primary data includes water usages, pump operation hours, load capacity of the submersible pump, usage of sprinkler systems, etc. The list of stakeholders includes farmers, equipment dealers, and authorities from electricity board.

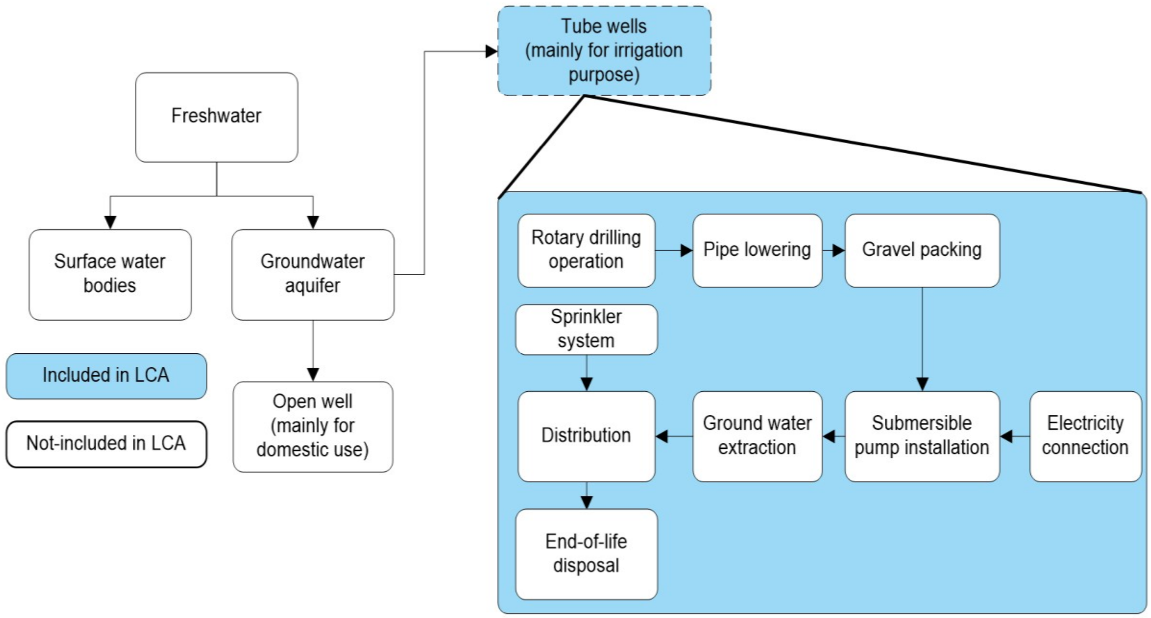


Figure 6.2. System boundary of the study

In total 58 stakeholders were interviewed, out of which 44 interviewees were farmers, 6 were equipment dealers, and 8 were from electricity board authorities of the district. The average semi-structured interview lasted about 25-30 minutes each. The energy consumption data have been collected by actual measurement and it was verified with the information provided by authorities of district electricity board. The secondary data for the study are collected through available online literature and equipment brochures. The energy consumption data is taken from billed usage of the consumers. Finally, the primary and secondary data were combined together to conduct the inventory analysis. The Ecoinvent datasets are used for modelling the energy and material flow model. Production and market activities from global dataset are used to model the data for well construction and, the data for Indian electricity mix has been considered to model the energy consumption for ground water extraction phase, and global dataset from Ecoinvent v3.0 database are used for distribution and end-of-life treatment phases. The functional unit of the study has been considered as 1 m^3 of groundwater (freshwater) extracted for irrigation purpose. The present study has carefully incorporated the life of equipment and materials, and their share in the extraction and distribution of groundwater, as shown in Table 6.1. The basic material and energy flow model of the study is shown in Figure 6.3.

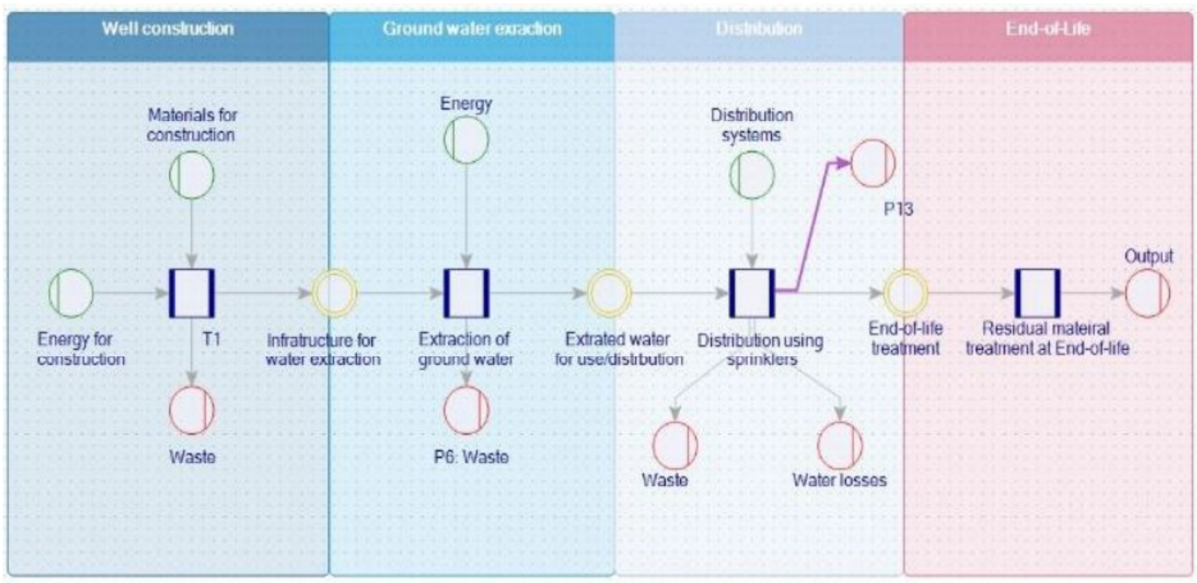


Figure 6.3. Basic material and energy flow model of the study

Table 6.1. List of main inventory analysis data used to model

S. No.	Product	Material	Quantity	Quantity for 1 m^3 water	Life in years
1	Pipe for well	Asbestos	37 Pipe/well	1.51 Kg	10
2	Packing for pipes in well	Gravel (1680 kg/m3)	62160 Kg/well	15.5 Kg	10
3	Electric Cable	Plastic	246 gm per meter	0.025 Kg	5
		Copper	164 gm per meter	0.015 Kg	5
4	Transportation	Transport lorry 3.5-7.5	600 Metric ton*km	0.15 Metric ton*km	-
5	Submersible Pump	Copper	15.44 Kg/pump	0.004 Kg	5
		Plastic insulation	1.56 Kg/pump	0.0004 Kg	5
		Steel	135 Kg/pump	0.034 Kg	5
6	Water	Withdrawal	22.17 m^3/hr	1 m^3	-
7	Sprinkler system	Nozzle	420 gm each	0.0015 Kg	5

		Foot button	100 gm each	0.0004 Kg	5
		GI Pipe + clip	960 gm per meter	0.0034 Kg	5
		HDPE Pipe	6 kg per 20 feet length	0.0986 Kgs	5
GI = Galvanized iron, PVC = Polyvinyl chloride,					

The above data is taken for a 40 HP submersible pump used to discharge 900 LPM water, upto a maximum height of 600 feet. Initially the data for well construction is collected for one well and the energy consumption data has been measured for random sample wells and verified afterwards with records of 687 wells from district electricity authority. It is assumed that each of the tube well runs for 6 hours in a day for 30 days, with an average discharge of 22.17 m^3/hr of groundwater. Hence, the total water withdrawal from the 687 tube wells in a month is estimated around 2741540 m^3. The LCA model has been developed for one cubic meter of water withdrawal (as shown in Table 6.1).

6.6 IMPACT ASSESSMENT

The well-known ReCiPe method has been utilized to perform the impact assessment (Huijbregts et al., 2016). Both midpoint and endpoint assessment have been carried out using ReCiPe method. In midpoint assessment nine categories are considered for assessment – climate change (CC – kg CO_2-Eq), fossil depletion potential (FDP – kg oil-Eq), freshwater ecotoxicity potential (FETP – kg 1,4-DCB Eq), human toxicity potential (HTP – kg 1,4 - DCB Eq), metal depletion potential (MDP – kg Fe-Eq), natural land transformation (NLT – m^2), ozone depletion potential (ODP – kg CFC-11 Eq), particulate matter formation (PMF – kg PM_{10}-Eq), and water depletion potential (WDP – m^3). Endpoint assessment results have been analysed under three categories: ecosystem quality, human health, and resources.

6.6.1 Midpoint Assessment Results

The midpoint assessment results have been analysed in this section.

6.6.1.1 Phase-wise Analysis

In phase-wise analysis, it is observed that the End-of-Life (EoL) phase has negligible impact on all the categories of midpoint assessment. The well construction (WC) phase has been found to have the highest impact, followed by ground water extraction (GWE), and distribution (D) phase. In well construction phase, the most significant factors for environmental impacts are packing of well, and consumption of copper, steel and fossil fuel. The energy consumed during extraction process is significantly affecting the environment in all the given categories. The phase-wise distribution of impact assessment is shown in Figure 6.4.

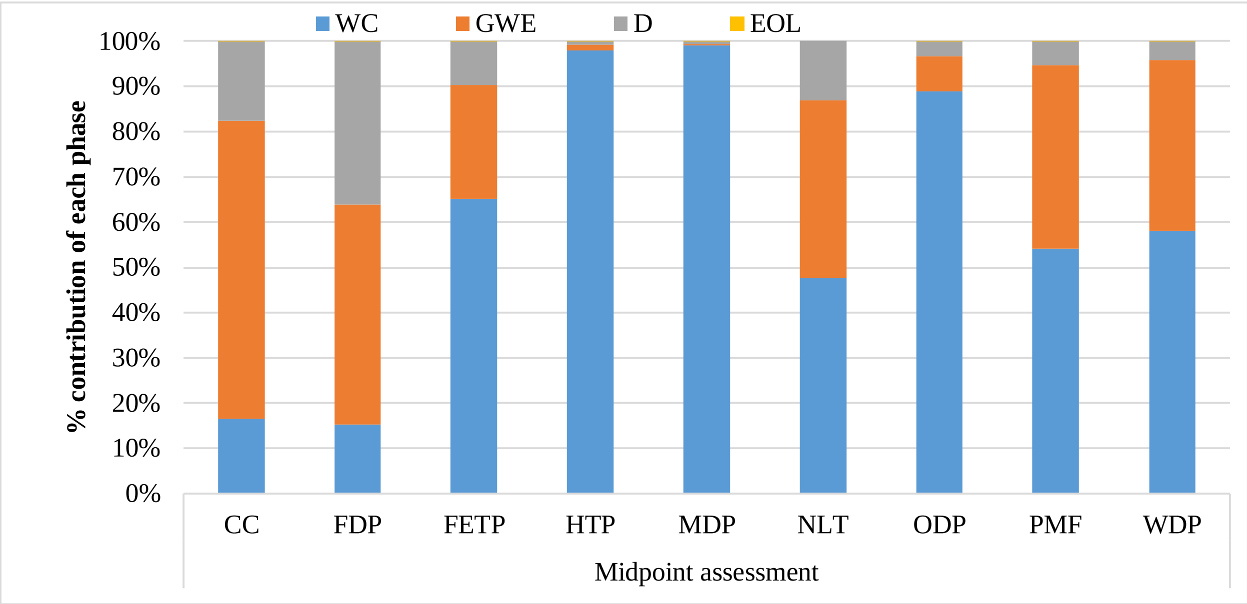


Figure 6.4. Phase-wise analysis of midpoint assessment

6.6.1.2 Categorical Analysis

It has been observed that the consumption of copper (used in submersible pump) has high impact during the entire extraction process under almost all the categories followed by distribution systems, and energy consumed in process of water extraction as described in Figure 6.5. After analysis, it is found that the toxic heavy metals used for copper processing are arsenic, cadmium, selenium, manganese, zinc, etc. are mainly responsible for the environmental impacts generated. Further the present study is compared with the findings of similar studies. Godskesen et al. (2018) used LCA to report that 0.00019 Kg CO_2 eq. is emitted for obtaining one liter of drinking water. The present study estimates the carbon footprint for one liter of groundwater in Indian context to be 0.00775 Kg CO_2 eq.

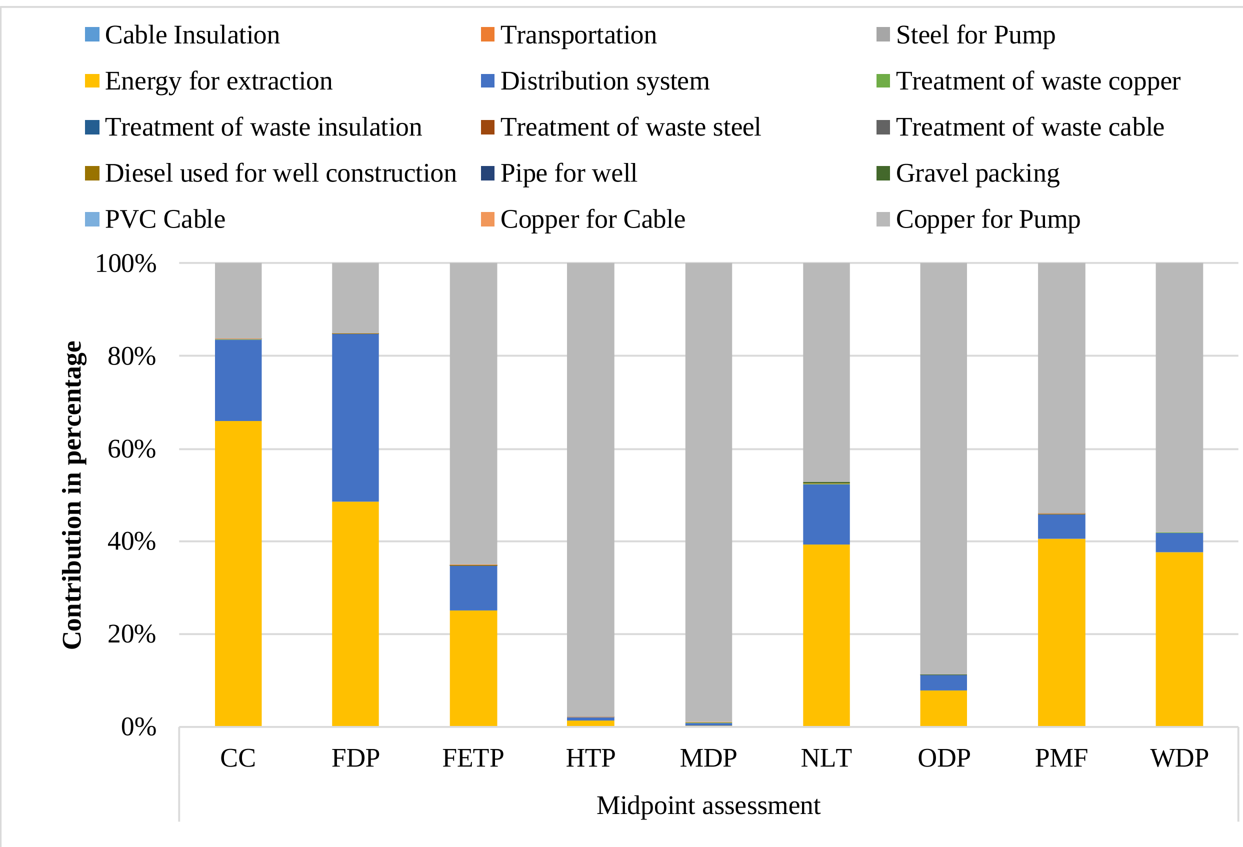
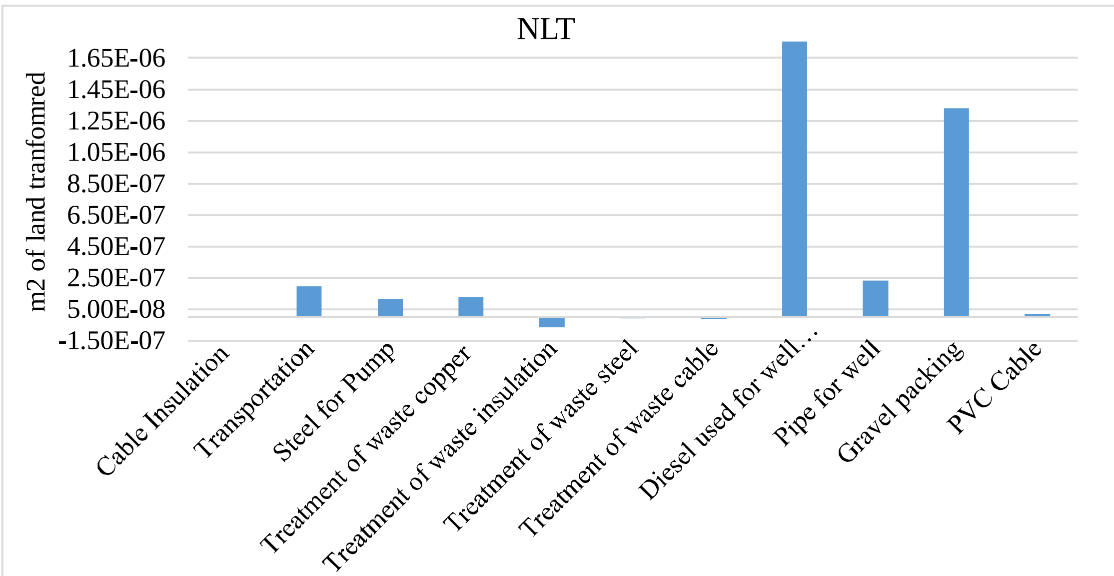
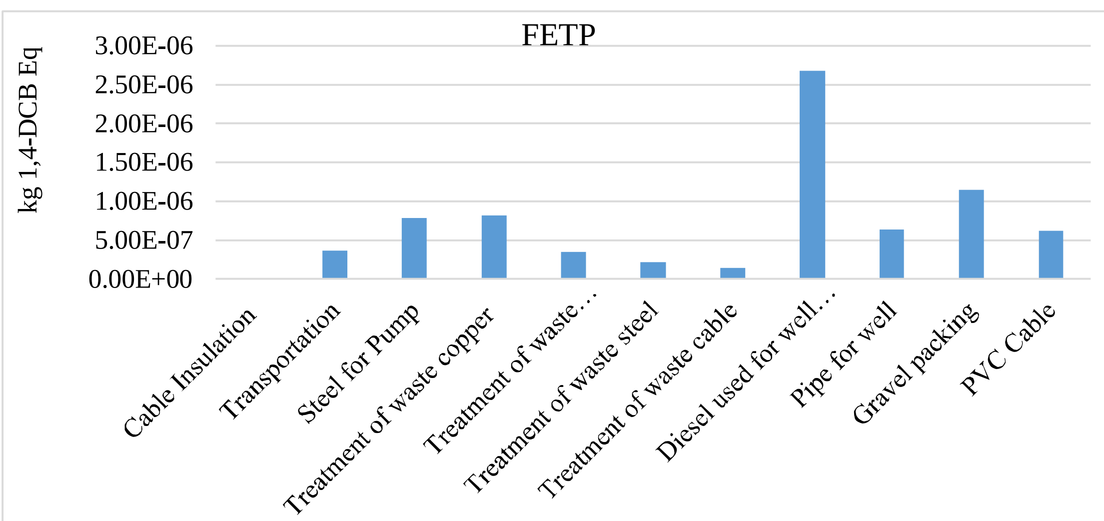


Figure 6.5. Category-wise analysis of midpoint assessment

To visualize the impacts of other model elements, two categories FETP and NLT are discussed in detail for brevity. After removing the most impacting factors in FETP category (copper, distribution system, and energy) from the results of midpoint assessment, it is observed that the consumption of fossil fuel used in the process is the most impacting factor followed by gravel packing, steel, PVC, and asbestos, as shown in Figure 6.6 (a).



(a)



(b)

Figure 6.6 (a-b). Analysis of NLT and FETP in midpoint assessment

In the category NLT, consumption of diesel and gravel packing have highest impacts, followed by asbestos, transportation, treatment of waste copper, and steel as shown in Figure 6.6 (b). It is also observed that treatment of insulation used in copper winding, waste cable, and waste steel are environmentally positive in the category of natural land transformation.

6.6.2 Endpoint Assessment

In endpoint assessment, the three main categories are ecosystem quality, human health, and resources.

6.6.2.1 Phase Wise Analysis

The phase wise analysis results with respect to all three categories are shown in Figure 6.7. In phase wise analysis of endpoint assessment, WC phase has highest impact on human health and resources categories, whereas ground water extraction phase has highest impact on ecosystem quality.

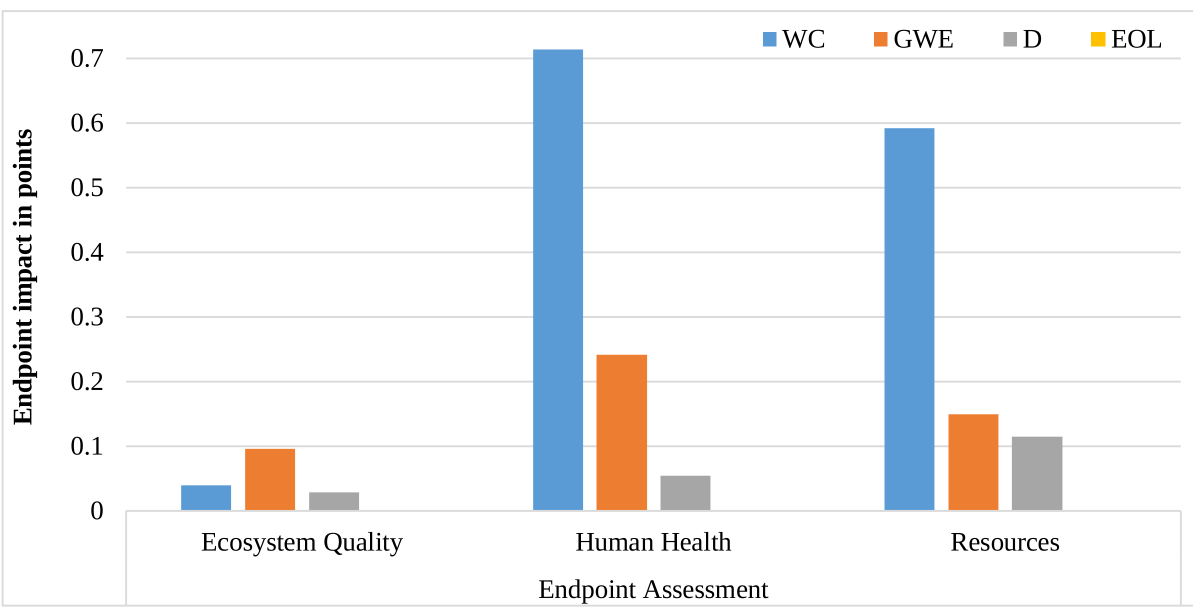


Figure 6.7. Phase wise analysis of endpoint assessment

The EoL phase has negligible impact in all the categories. Moreover, the results followed the same trend of midpoint assessment in the phase wise analysis.

6.6.2.2 Category Wise Analysis

In category wise analysis of the endpoint assessment, consumption of copper has been found as the dominating element for environmental impacts in the entire process. This has similar trend as obtained through midpoint assessment, i.e. the consumption of copper has highest impact followed by energy consumed in the process, and distribution system. In the distribution system, HDPE pipe used for irrigation purpose has been reported as one of the substantial environmental hazards. The category wise analysis of endpoint assessment is shown in Figure 6.8.

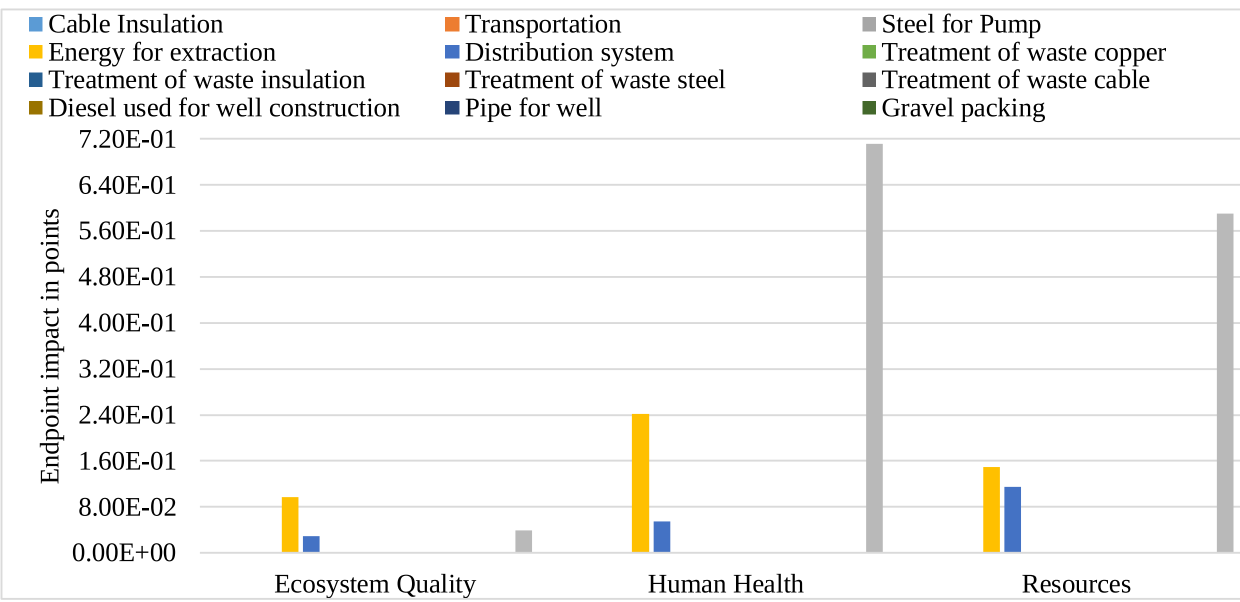


Figure 6.8. Category wise analysis of endpoint assessment

After removing the three major contributors copper, distribution system, and energy consumed in extraction, the graphs are again plotted with respect to the three categories as shown in Figure 6.9. From the results, it has been observed that similar to midpoint assessment, endpoint assessment also prescribes transportation, PVC cable, packing for well, steel for pump as the main contributors to the environment threats.

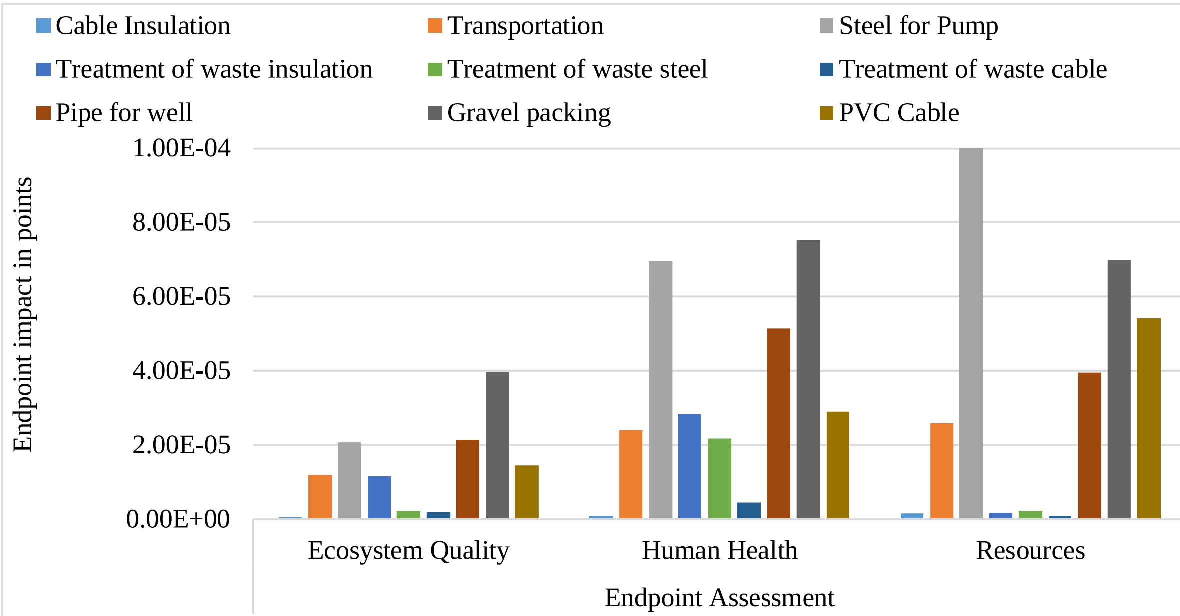


Figure 6.9. Categorical analysis after removing the major contributors (copper, energy etc.)

To assess the impact of water withdrawal, there are various categories and assessment methods. One of the indicators is – Available WAter REmaining (AWaRE) indicator developed by the WULCA (Water Use in LCA), which is a working group of the UNEP-SETAC Life Cycle Initiative (Godskesen et al., 2018). Volume of freshwater can also be considered as water footprint measure, as considered in the present study. The water footprint of the current study has been assessed by WDP category of ReCiPe method. It is found that total water depletion potential value of extracting one litre of groundwater is 1.05 m^3.

6.7 SUMMARY

In the present study, environmental impacts are assessed for one kilolitre of groundwater used for agricultural purposes in hyper arid region. The study use LCA methodology for the assessment. Software tool Umberto NXT universal and Ecoinvent dataset v3.0 are used for energy and material flow modelling, and well known ReCiPe method is utilized for impact assessment. This study used the global or European data wherever the Indian data was not available in Ecoinvent v3.0.

The findings of the study show that well construction phase has highest impact towards environment hazards. Consumption of copper in equipment throughout the process is the most impacting factor to affect overall categories considered for this research work. This is due to the heavy toxic metals used in its processing. It is observed that heavy metals are easy to identify, process, and work with, which makes them the first choice for any manufacturer. Even though silver is also a good conductor over copper, but its usages are limited due to high cost associated. Secondly, energy consumption plays a key role affecting all the categories of midpoint and endpoint assessment. Results of the present study are comparable to the study by Mo et al., (2011), where embodied energy consumption for a unit water withdrawal from surface water aquifer and ground water aquifer is compared. It is found that the energy consumption is more in the case of groundwater, which is due to the high pumping requirements. The results of the present study can help researchers as well as practitioner (farmers) to develop an understanding of water energy nexus in water scarce regions.

The outcomes of the study demand a suitable groundwater withdrawal policy as the total habitation and agricultural water needs are fulfilled by groundwater only. Along with groundwater extraction, water quality issues are yet to be explored and addressed due to large amount of pesticides and herbicides used for agricultural production in the area. Dependency on groundwater resource in the area clearly demands addressing the issues related to quantity and quality of the subsurface water, so that groundwater can be preserved and sustained for future generations. Another possible solution in semi urban regions is to use treated wastewater for irrigation purposes, which also contains required nutrients for the growth of crops. The after effects of using a treated wastewater in context of social and environmental aspects can be studied further.

Technically tube wells for groundwater extraction should be allocated after analysing the pump test records/reports of the aquifers, so that the groundwater withdrawal rates from the aquifer can be checked. Along with this, the present practice of sprinkler irrigation system should be replaced by drip irrigation system in order to save a huge amount of water in irrigation systems. Solar powered pumps can be a good alternate for distributing the stored water for irrigation. The study limits to environmental impacts assessment and do not consider socio-economic aspects of the groundwater withdrawal/usage.

The next chapter of the study will discuss the chapter wise conclusions of the research work carried out in this thesis along with its limitations and future research direction.