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Environmental Impacts of Natural Dyeing Process Using Pomegranate Peel Extract as a Dye

M.Anandhan [1], T.Prabaharan[2]

[1, 2,] *Department of Mechanical Engineering,*
Mepco Schlenk Engineering College, Sivakasi, India.

Abstract

Natural dyes are gaining popularity due to less environmental burdens but can be applied on textiles only with the help of metallic mordants. Pomegranate peel is selected as the source of natural dye due to its great success in the application of textile dyeing from old times. In this research work environmental impacts due to pomegranate dyeing in textile using Aluminium Sulphate mordant are studied and documented. Since the objective of the work is to study environmental impacts for the entire life cycle of the processes Life Cycle assessment is chosen and carried out. The system boundaries considered were pomegranate cultivation, harvesting, grinding of pomegranate peel, dye extraction, pre-treatment of fabric, dyeing, dye fixing, washing and drying of fabric. The inventory data for impact calculation were taken from laboratory scale experiments for the extraction of dye, pre-treatment & dyeing of fabric. The inventory data for pomegranate cultivation and harvesting were taken from literature. Extraction of colour component from Pomegranate peel was performed by boiling with water and the extracted aqueous solution is used for dyeing. Various shades of yellow colours are obtained with the help of mordants which is added to the fabric after it's pre-treatment. Conducting Life Cycle assessment (LCA) is meaningful only when dyed fabric is having good colour fastness property. So the colour fastness properties of the dyed cotton fabric with different mordants such as Eucalyptus bark extract, Aluminium Sulphate, Copper Sulphate, and Ferrous Sulphate etc. have been studied and found to be acceptable. The environmental impacts due to water usage and carbon footprint for the above inventories were estimated and documented. The functional unit considered was dyeing of 1 tonne of cotton fabric with acceptable colour fastness property. The LCA software tool used was CCALC2. The estimated values of total Carbon foot print and total water footprint are 1.11x105 $kgCO_2$ eq/fu and 1.47 $x10^5$ m3 water eq/ fu respectively. The other environmental impacts estimated were Acidification potential, Eutrophication potential, Ozone layer depletion potential, Photochemical Smog Potential and Human Toxicity potential.

Keywords: Life Cycle Assessment , Carbon foot print,Natural dye, Mordant, Cotton fabric

INTRODUCTION

The study of environmental impacts is very essential for sustainable development in any field. In textile industry environment degradation occurs at different stages of production. Textile dyeing is one such process which require huge quantity of water, energy for heating and dye chemicals leading to significant environmental impacts.

The global consumption of textile in the year 2009 is estimated at around 30 million tonnes, which is expected to grow at the rate of 3% per annum [1]. The domestic textile industry in India will reach US$ 250 billion by 2019 and Textile and apparel exports from India is expected to increase to US$ 82 billion by 2021 from US$ 36.66 billion in Financial Year 2017 [2] which emphasizes the need for huge quantity of textile dyes in the future. The colouration of huge quantity of textiles needs around 7,00,000 tonnes of dyes and reasonable amount of metallic mordants which causes release of vast amount of unused and unfixed dyestuff, metals into the environment. [1]. According to the statistics provided by Ministry of Chemicals & Fertilizers Department of Chemicals & Petrochemicals, in India around 320,000 Metric Tons of Dyes and pigment chemicals were produced during the year 2016-2017 [3]. Due to rise in consumption of colourants the demand gets increased in textile dyeing industries. The U.S based survey group "The Freedonia Group" states that, in the year 2013 there was 3.9% of demand in synthetic dye chemicals all over the world and it may rise to 6% ($19.5 billion) in 2019 [4]. Global textile consumption is estimated to amount to more than 30 million tons a year, making it very much important to look into the issue of environmental impact during production , maintenance , usage and eventual disposal stage stressing the need for radical change in textile and clothing industry [5] [6]. Thus there is a huge demand for textile dyes in the future and there is a need to assess the environmental impacts in the processes due to the usage of huge volume of dyes.

Synthetic dyes are obtained through chemical reactions in factories. Due to its ready availability and cost advantage most of the textile manufacturers have shifted from natural sources to synthetic dyes. In recent times Natural dyes are gaining popularity due to their less environmental burdens. However they can only applied on textiles with the help of metallic mordants. Use of metallic mordants is involved with the release of some harmful and polluting chemicals in to the environment during their dyeing process.

Before the invention of synthetic dyestuffs, natural colours were used in India for centuries. Natural dyes are known for colouring the food substrate, leather as well as natural fibres like wool, silk and cotton [1], [7]. Hence worldwide, growing consciousness about organic value of eco-friendly products, has renewed the interest of consumers towards use of textiles dyed with natural dyes [7].Natural dyes are mostly applied on textiles by the help of mordants. With the help of mordants different colours and shades can be obtained with the single dye source by varying its concentration and using combination of various similar mordants. The process of Mordanting can be achieved in three different methods, pre-mordanting, simultaneously mordanting and post mordanting [1]. Natural dyes are derived from sources of the plants, trees, insects and minerals. The dyes are basically classified into two groups as natural dyes and synthetic dyes. Pomegranate (Punica granatum) is one such source and its rind has been successfully used in the extraction of natural dyes for coloration purpose since ancient times. The important coloring components present in the pomegranate peel are tannins and flavonols.[8] Pomegranate is known to originate in Iran or Persia. At present India and China are the leading countries in the cultivation and production of pomegranate. Pomegranate is very popular in Europe and in various other countries for manufacturing syrup, fresh cereal jelly and wines. It is also extensively used in the manufacture of ayurvedic medicine. Pomegranate is not suitable for humid conditions and high rainfall zone. It is best suited for planting during the months of June and July. It adapts very well to low fertile soils and comes up well in dry land. India is the largest producer of pomegranate [9] and produces 745000 tonnes annually which is a 50 % of world production. It needs less water and thus a attractive option for farmers to grow. In India it is cultivated in large quantity in Maharashtra, Karnataka Andhra Pradesh, Madhya Pradesh, Rajasthan, Gujarat and Tamilnadu. Even though it stands at eighteenth place in the world fruit consumption there is a huge potential to use its peel for natural dye production.

In this investigation life cycle assessment of textile dyeing using Natural dye extracted from pomegranate peel using Eucalyptus bark extract as natural mordant along with metallic mordants is investigated. Pomegranate is selected due to its great success in the application of textile dyeing from old times. India is rich in biodiversity and plenty of Natural resources are available for use in natural dyeing processes. Also it is very much essential to carryout life cycle studies in order to have sustainable textile dyeing process.

Life cycle approach is adopted for the application of natural colorant obtained from pomegranate peel on 1000 kg of cotton fibre. The Life cycle assessment is carried out for energy and greenhouse gas emissions.

Life cycle assessment (LCA) is an analysis method to evaluate potential environmental impacts of a product or process. The processes considered are Pomegranate cultivation, harvesting, cutting of pomegranate rind, grinding, colour extraction and application of colorant on the fabric. The impacts due to the natural mordant cultivation and processing are excluded from the study due to less requirement of mordant. Also storage and usage stage of dyed fabric were not used in the life cycle assessment study. LCA for Natural colorant is not extensively discussed in literature and this is an attempt to carry out a LCA using inventories obtained from laboratory scale experiments and literature.

LCA studies on the application of natural resources are extensively discussed in various works.[10][11][12]. Kumar et al [10] discussed a LCA for Jetropha biodiesel production in India.

In this investigation the system boundary is cultivation, harvesting, cutting of pomegranate rind, grinding, colour extraction, pre-treatment of fibre by mordanting and post treatments, colorant fixing and application of colorant on the fabric. The system boundary is shown in the figure 14.

The functional unit is 1000 kg of cotton fibre to be dyed with acceptable colour fastness property. The impact categories chosen are global warming potential, Eutrophication, and human toxicity potential. The study is cradle to gate, as impact due to usage stage of dyed fabric is excluded from the system boundary. Also the cultivation process assumed to have zero usage of pesticide. Various methods such as IMPACT 2002, CED, Recipe 2016 and Eco Indicator 99 are available for conducting life cycle assessment. Following midpoint impact categories were considered for the study

1. Carbon foot print
2. Acidification potential.
3. Water usage and water footprint
4. Eutrophication
5. Photochemical Smog potential
6. Human Toxicity potential.
7. Ozone layer depletion potential

In this work the Carbon Foot printing Tool (CCaLC2) tool is used to perform a LCA. CCaLC2 is a simplified LCA tool for identifying ‘carbon hotspots’ as well as more comprehensive measurements (e.g. water footprint) [13]. It is a support tool for calculating and reducing the carbon footprints of different industrial sectors along complete supply chains. It includes the ecoinvent database and CCaLC2 database which are used during different estimations.

MATERIALS AND METHODS

Material

The plain cotton fabric is obtained from commercial textile shop, virudhunagar. Eucalyptus bark, Pomegranate peel collected from rural area in virudhunagar, is used for the study. All other chemicals including mordants used were of laboratory grade.

Textile sample preparation:

The plain cotton fabric is obtained from commercial textile shop Virudhunagar. It is used for the study. The cotton fabric is washed gently with 10% soap solution at in 60ºC for 1 hour. Then the fabric is dried under shade. Fabric is cut-down to the size of 10cm x 5cm and weighed by using digital weighing balance. The weight of the single sample is 0.8g.

Dye Extraction

By using mixer grinder the Pomegranate peel sample is ground and powdered Pomegranate peel dye stuff is obtained. 5g of

Pomegranate peel powder along with 100ml distilled water is heated at 90ºC and continuously stirred for 1 hour by using hot plate with magnetic stirrer. The resulting coloured (yellow) solution is filtered by plain cotton fabric and the extracted aqueous solution is used for dyeing.

Preparation of Eucalyptus bark extract

Eucalyptus bark is collected from rural area in virudhunagar. By using mixer grinder the eucalyptus bark is grounded and powder is obtained. 5g of eucalyptus bark powder along with 100ml distilled water (5% solution) is heated at 90ºC by continuously stirring it for 1 hour by using hot plate with magnetic stirrer. The resulting solution is filtered and the extracted aqueous solution is used for mordanting.

Mordanting with Eucalyptus bark extract

The extracted aqueous solution is used for pre, simultaneous and post mordanting the textile sample. Five samples (10cm x 5cm) are taken for mordanting process. The samples are immersed in the mordanting solution and continuously stirred for 15 minutes. After that samples are taken out from the mordanting bath and they are dried under shade

Dyeing of mordanted cotton fabric

Mordanted cotton samples were soaked in the dye bath containing extracted dye material at pH 7. The M:L ratio was kept at 1:20 and the temperature of the dye bath was maintained at 50ºC for 60 minutes. In order to get uniform dyeing the samples were stirred continuously. The dyed cotton samples were dried under shade at room temperature

Textile sample testing

There are different types of tests available to evaluate the dyed textile samples such as colour fastness to washing, rubbing, perspiration and hot pressing etc.

Washing test

The samples were subjected to observation of different stages of successive washing. Textile sample is immersed in the soap solution for 5 min and stirred continuously after that taken out from the washing bath and the Sample is dried under shade at room temperature

Calculation of life cycle Inventories:

For 1000 kg of cotton fibre by using 1:20 MLR 20000 litre of dye solution is needed. In order to prepare the above quantity of dye solution 1000 kg of pomegranate peel powder is needed. Assuming an average weight of 40 g of rind per fruit the number of fruits needed to dye 1000 kg of cotton fibre is 25,000. A 5 year tree may yield 100 fruits per year per tree. Since 100 trees can be planted per acre for medium dense the land use requirements comes to 2.5 Acres. The water requirement for the 5 year old tree needs 32 litres per day. Thus for the year 11680 litres of water are needed / year for a tree. So for 250 trees 29,20,000 litres of water is needed for irrigation alone. For dyeing and simultaneous mordanting we need 20,000 litres of water. For washing after dyeing another 20000 litre of water may be used. The fertilizer dose required for 5 year tree were 600-700 g N, 200 – 250 g of P_2O_5 and 200 – 250 g K_2O, 10 kilo gram of farm yard manure and 75 g of ammonium sulphate. [14] Assuming a need to transport a distance of 100 km approximately 12 kg of CO_2 emission is obtained. Since for transport data of 1 tonne km, 0.12 kg CO_2 is released.

The list of inventories used for various unit processes in the LCA study are given in the Table1.

RESULT AND DISCUSSION

Pomegranate peel extracts dye and its results

Pomegranate peel extract as a natural dye is used for dyeing the cotton fabric with the help of eucalyptus bark extract as a mordant. The dyed samples are subjected to observation of different stages of successive washing. Based on the mordanting process it gave various shades of yellow colour. The figure 1 shows the colouring effects of pomegranate peel extract in cotton fabric.

Table 1. List of inventories used for various unit processes in the LCA study.

Sl.No	Name of Inventories	Per FU
1.	Sodium chloride	40kg
2.	Soap	20kg
3.	Tannic acid	40kg
4.	Urea	339.062 kg
5.	Phosphoric acid	120kg
6.	MOP (Muriate of Potash)	105.8 kg
7.	Water requirement for cultivation	15,62,500 litres
8.	Land use	2.5 Acres
9.	Alum / Stannic Chloride / Stannous Chloride	40 g
10.	Energy Requirement for Dyeing	420kWhr
11.	Energy Requirement for Dye Extraction	315 kWhr
12.	Transport	12 $kgCO_2$eq.
13.	Energy Requirement for Desizing and Scouring	10GJ/Tonne
14.	Water requirement for Mordanting, Washing, Desizing, cleaning with soap solution	100000 litres

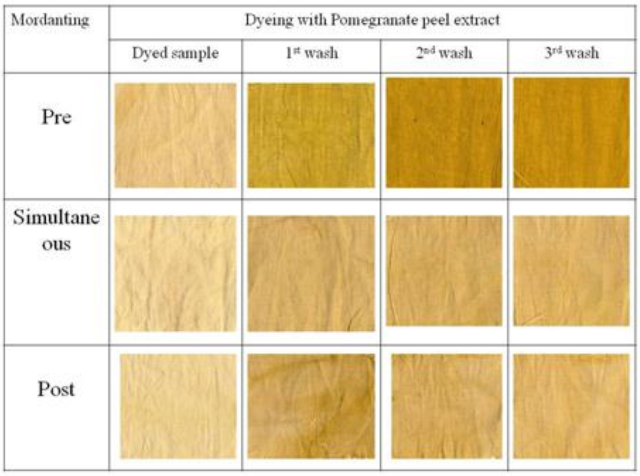

Figure 1. Colouring effects of Pomegranate peel extract dye.

Based on the washing results the simultaneous mordanting Process gave better colour fastness to washing compared to pre and post mordanting process. For arriving better colour fastness dyeing was done by varying Concentration of the Pomegranate peel extract (5%, 10%, 15%) and mordanting was done by same concentration (5%) for all the three processes. The dyed samples are subjected to successive washing and their results are summarized in the figure 2.

Bleeding was observed in the successive washing test. For increasing the colour fastness properties salt mordants are included in the mordanting process. Aluminium sulphate, Copper sulphate, Ferrous sulphate are also used in this study. Based on the mordants the Pomegranate peel extract dye gave Bright yellow, Brown and Dark blue colour. The dyed samples are subjected to successive washing test .The results are summarized in the Figure 3.

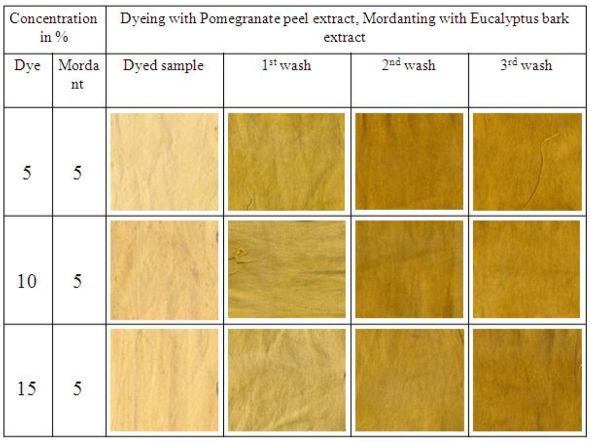

Figure 2. Colour fastness to washing results for varying concentration of Pomegranate peel extract

Figure 3. Colour fastness to washing results using salt mordanting process

From the above figure 3 we can infer that, use of additional salts in the mardanting process (Aluminium sulphate, Copper sulphate and ferrous sulphate) gave better colour fastness properties compared to without salts in the mordanting bath. Use of these salts in the mordanting bath enriches the dye uptake of the cotton fabric and evenly distributes the dye content in the cotton fabric. So we are in need of that salts. These dyeing and mordanting experiments were used for inventory data for dyeing processes in the LCA study.

The principal inventory and environmental impacts are water usage, dye material needed, CO_2 emissions, chemical requirement were found out and documented.

CONCLUSION

The environmental impacts for the textile dyeing using pomegranate is studied and explored. Using eucalyptus bark extract as mordant along with different metallic mordants and the Pomegranate peel extract as a Natural dye gave various shades of yellow colour. Based on the washing test results simultaneous mordanting gave better colour fastness to washing compared to pre and post mordanting techniques. Increasing the concentration of the pomegranate peel extract dye gave various shades of yellow colour. By adding the salt mordants like Aluminium Sulphate, Copper sulphate, Ferrous Sulphate gave better colour fastness to washing. We obtain better colour fastness to washing with this salt mordants in minimum concentration.These experimental data and data available in the literature were used for this LCA study. For optimised conditions impacts were calculated using the software CALCL2 which uses ecoinvent database, user defined database and CCaLC2 database. The total water needed is estimated to be 29,20,000 litres per 1000 kg of cotton fibre excluding the inventories of cotton. For transportation carbon foot print comes to 12 kg of CO2.

The estimated environmental midpoint impacts obtained from the LCA study using the software CALCL2 is shown in the table 2 and in various figures from figure 4 to 13.

Table 2. Mid Point Impact categories of dyeing 1 tonne of cotton fabric using Pomegranate peel extract.

Sl.No	Midpoint impact categories	Per Functional unit
1.	Carbon foot print	$1.11 x 10^5$ $kgCO_2$ eq/fu
2.	Water usage	1.54×10^5 m^3 water /fu
3.	Water foot print	$1.47 x 10^5$ m^3 water eq/ fu
4.	Human Toxicity Potential	4104kg dichlorobenzene eq/fu
5.	Acidification Potential	68.2 kg SO_2 eq /fu
6.	Photochemical Smog potential	0.621 kg ethene eq/fu
7.	Ozone layer depletion	$7.32 x 10^{-4}$ Kg R11 eq/fy
8.	Eutrophication	22.5 kg phosphate eq /fu

The principal results of the estimation are

- Total Carbon foot print $1.11 x 10^5$ $kgCO_2$ eq/fu
- Total water usage 1.54×10^5 m^3 water / fu
- Total water footprint stress weighted is $1.47 x 10^5$ m^3 water eq/ fu

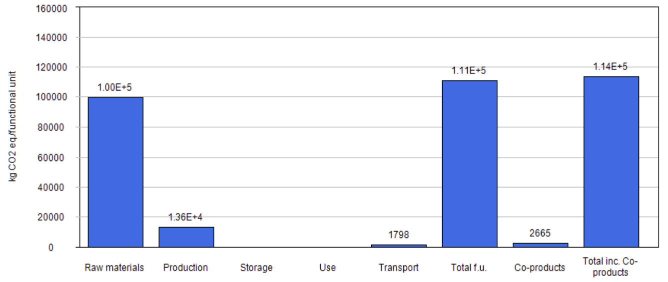

Figure 4. Carbon Foot print

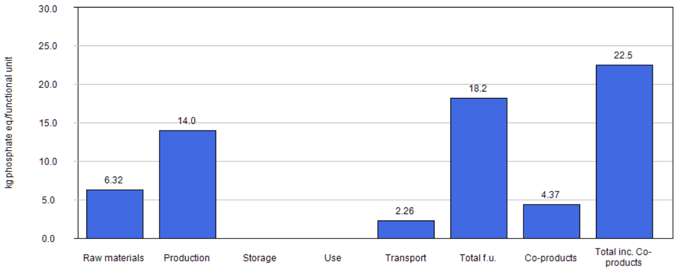

Figure 6. Eutrophication

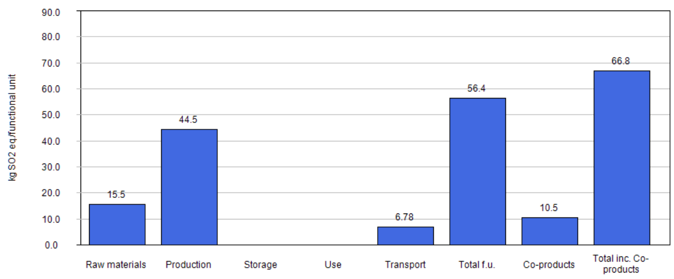

Figure 5. Acidification potential

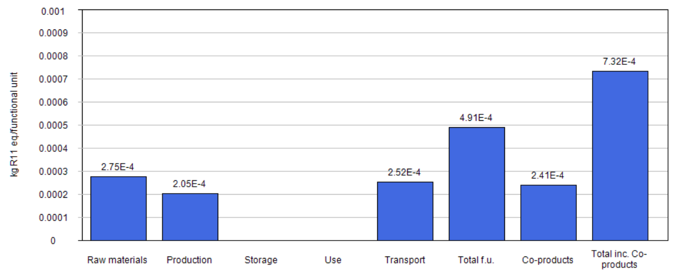

Figure 7. Ozone layer depletion potential

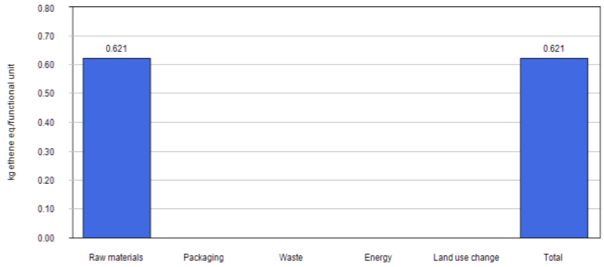

Figure 8. Photochemical smog potential

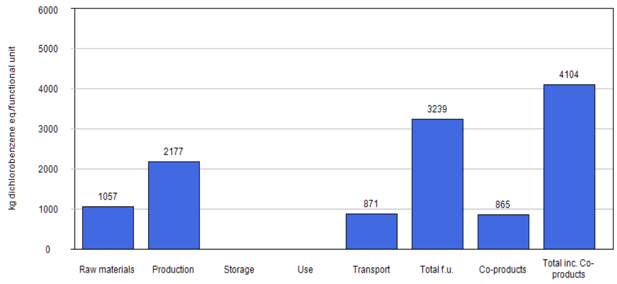

Figure 9. Human Toxicity Potential

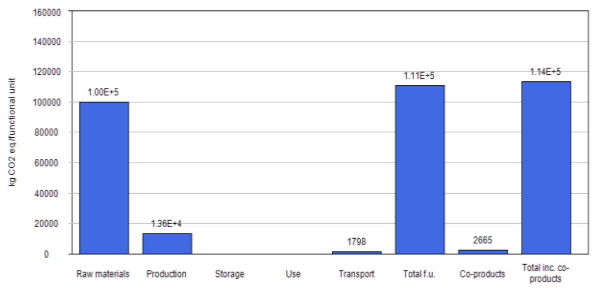

Figure 10. Summary of carbon foot print

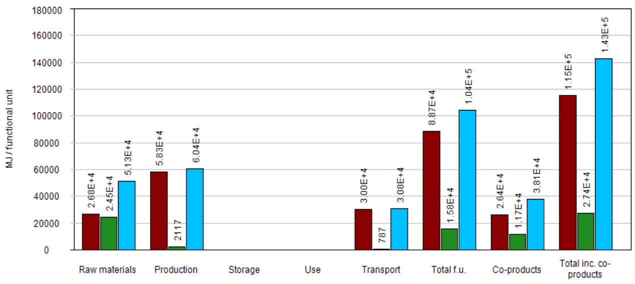

Figure 11. Summary of cumulative energy demand

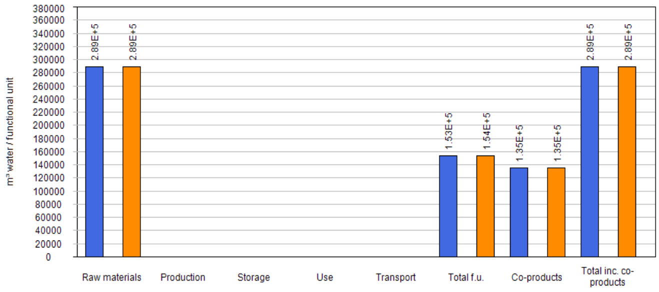

Figure 12. Water Usage by stage (m^3/Functional unit)

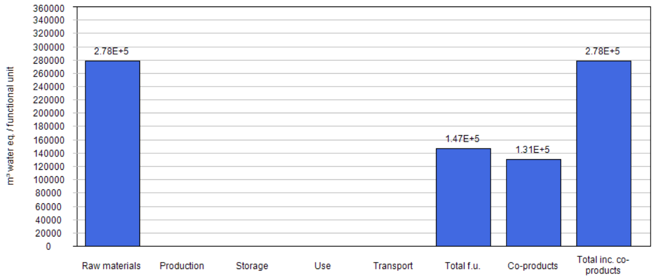

Figure 13. Water Foot print stress weighted

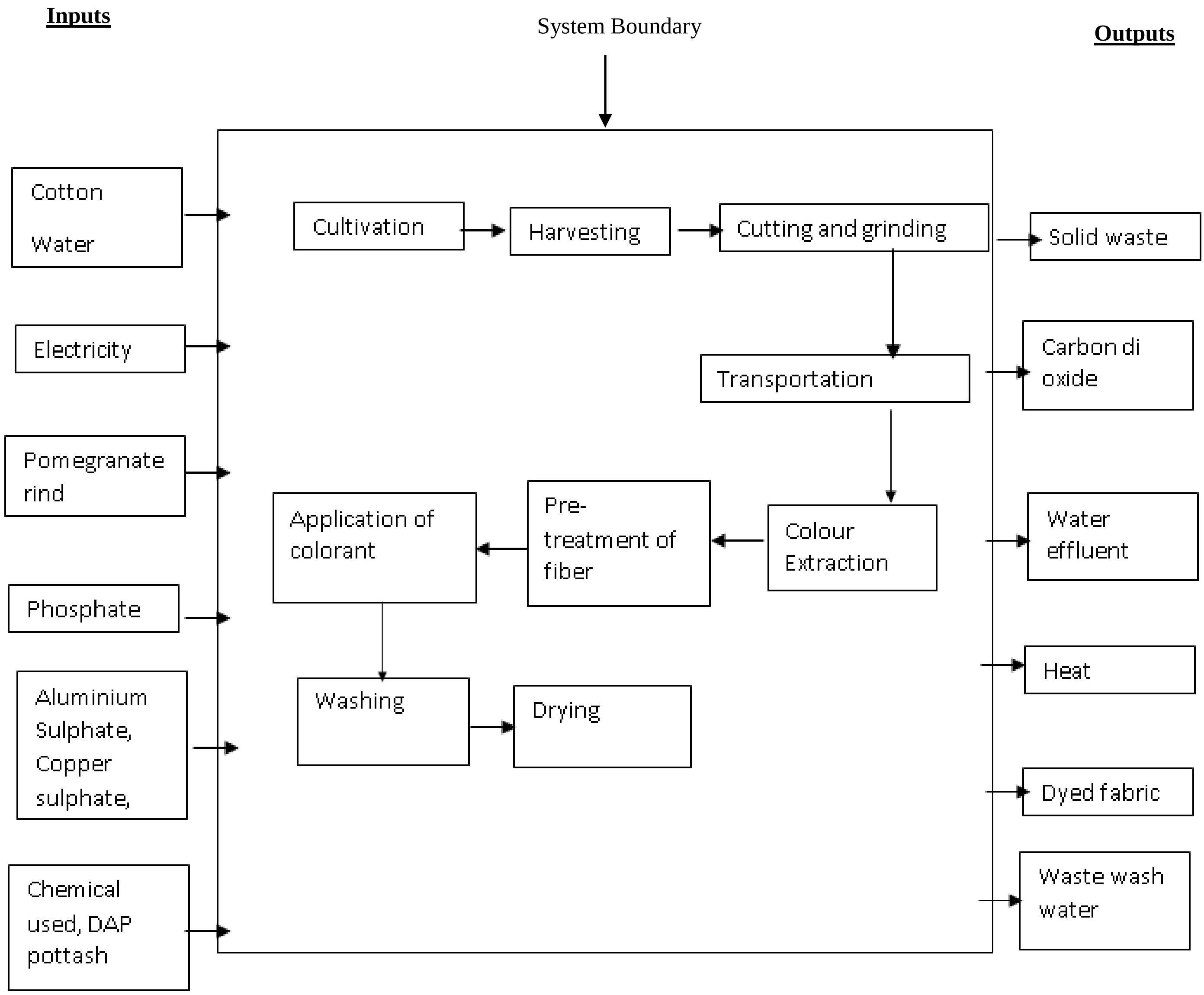

Figure 14. System Boundary for LCA study.

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