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(RESEARCH ARTICLE)

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Linear programming for cost effective biomass production from water hyacinth- *Eichhornia Crassipes*

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Abstract

The production of biofuel has advanced significantly in recent years, while the cost and availability of fossil fuels have increased. The most affordable and widely accessible resource is biomass and biofuel. An unpleasant water weed that grows in large quantities in India, water hyacinth can be exploited to make biogas to provide electricity and biofuels to power motors and cars. In this study, we provide a summary of the barriers to biomass production and consumption as well as a mathematical modeling of water hyacinth biomass production. The multi-objective linear programming technique is used to formulate the entire biomass plant construction concept.

Keywords: Water Hyacinth; Biomass; Mathematical modeling; MOLP

1. Introduction

India and other tropical nations are home to large populations of the infamous aquatic weed known as water hyacinth, or *Eichhornia crassipes*. Other names for it include poisonous plant, Bengal horror, and blue devil. A major danger to biodiversity, this water hyacinth is frequently held responsible for choking water bodies and causing issues for other water bodies. It is typically found in freshwater environments, which can range from big lakes and rivers to little ponds and ditches. Even rice fields are infested by the plant. But recently, its environmental value has been acknowledged as a fantastic biomass that may save 7.3 tons of firewood year.

2. Loathsome activity of Water Hyacinth

The water hyacinth is regarded as the world's worst aquatic plant. In addition to causing ecological and physical issues, it also affects the economy. Its dense green mats obstruct waterways, making it difficult to fish, boat, and engage in any other water-based activity. When these plants obstruct drainage, the risk of flooding rises. In addition to being breeding grounds for mosquitoes that spread encephalitis and malaria, clogged water bodies raise the risk of water-borne illnesses. Because of their huge leaves, water stagnates, creating the perfect environment for mosquito larvae to thrive. Additionally, it keeps oxygen and sunshine out of the water.

Therefore, when these plants choke water bodies, fish and other aquatic animals die. Other submerged plants are pushed away or crushed by an acre of water hyacinth that weighs more than 200 tons. In 50 days, one blossom yields 1000 young plants. Other native plants that the animals and birds rely on for refuge and nesting are eradicated. In addition to making water bodies shallow, the massive amount of water hyacinth has a negative effect on agriculture,

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particularly rice farming. When massive water hyacinth pushes tons of water into the land during the rainy season, farmers face numerous challenges. The production of hydroelectric power is also impacted by the lush growth of water hyacinth. The weed's ability to adapt has allowed it to live in all kind of freshwater ecosystem on the planet. This weed requires a lot of money and effort to remove.

The current statistical data on the growth of Water Hyacinth in a large country like India is tabulated below.

Table 1 Statistical data - Availability and composition of Water Hyacinth

Parameter	Statistics	Source
Growth Rate	150 metric tons of fodder per hectare annually	[1]
Doubling Time	14 days in India	[2]
Maximum Doubling Rate	9.6 to 10.8 days under optimal conditions	[2]
Water Evaporation impact	Can increase water evaporation up to 2.5 times faster	[3]
Moisture content	90 – 95%	[4]
Dry matter	5-10%	
Ash content	15- 25 % of dry matter	
Crude Protein	10-20% of dry matter	
Crude Fibre	20-35% of dry matter	
Lipids	1.5 – 3%of dry matter	
Carbon C	35 – 40 %	[4]
Hydrogen H	5-6%	
Oxygen O	30-35%	
Nitrogen N	1.5-3%	
Sulfur	0.2-1%	
Potassium K	1-4%	[5]
Calcium Ca	1-3%	
Magnesium Mg	0.5-1%	
Phosphorous P	0.5- 1%	
Sodium Na	0.1 – 0.5%	
Capable of absorbing Cadmium Cd, Chromium Cr, Copper Cu, Mercury Hg, Lead Pb, Zinc Zn	less quantity	[5]

3. Cause and Control of Water Hyacinth:

The growth rate of water hyacinth is influenced by water nutrient levels, plant density, solar radiation, and season. Temperature and water nutrient concentration were found to be the most important factors in the growth rate of water hyacinth. Increases in water nitrogen increase the growth of water hyacinth. Overall, water hyacinth is a symptom rather than a problem; the real issue arises from human disposal of untreated sewage water into water bodies and excessive fertilization of the water, which allows the plant to grow in large quantities.

Its growth can be managed chemically, physically, and biologically. Because of its unknown long-term effects on the environment and communities it comes into touch with, chemical control is least preferred. On the other side, physical control, which is commonly utilized but expensive, time-consuming, and only provides temporary solutions, includes mechanical mowers, dredging equipment, and manual extraction. Utilizing host-specific natural enemies to lower population density is known as biological control. It has been determined that a number of fungi and insects can manage this plant. The development of a biological herbicide from a locally occurring pathogen is underway in Kenya.

4. Chemical composition of Water Hyacinth:

Water Hyacinth is rich in hydrocarbons which are essential for methane production [6]. Its cellulose content is used for the production of biofuel and paper production .The composition is shown below in figure 1.

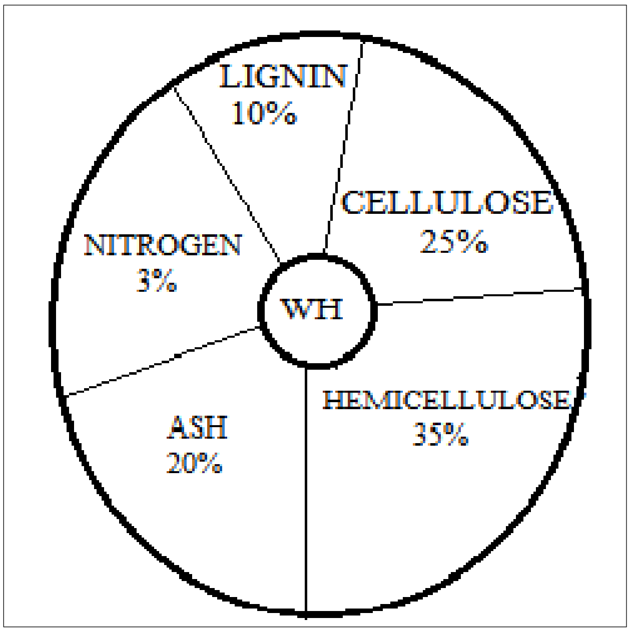

Figure 1 Composition of Water Hyacinth

5. Review of literature

Kondula Ruthala a NRI from Andra Pradesh offers a solution. He proposes use of biogas production from Water Hyacinth to be used for generating electricity, heating and industrial purposes. He aims to produce efficient energy solutions that are reliable, scalable and cost effective . The government spends about 10 lakh rupees to 15 lakh rupees every year on removal of Water Hyacinth. Mr.Ruthala proposes to produce 10,000 cubic meters of raw gas and 50 tons of manure every day besides reducing green house effect, odors and pathogens. [The Hindu, 2021]. The firm in Thoothukudi, Tamil Nadu initially produced biogas using food waste and cow dung but now they switch over to Water Hyacinth and were successful. Cleared Water Hyacinth is dried and placed in a biogas plant. The furnace acts as an anaerobic reactor. Nickel is added to it and when entry of air is blocked it starts fermenting and produce gas in less than 24 hours. Biogas in its raw form contains methane, carbon dioxide, sulphur and dust. It is extracted and purified till pure methane is extracted. This methane can be stored in cylinders and be used as electricity and as cooking gas. Researchers in this field say that a 14 Kg cylinder can be supplied at approximate of 250 rupees each while the LPG cylinder with subsidy is sold for 390 rupees.To improve biomass quality application of silage additives has played an important role. Nutrients, fermenting acids, bacterial inoculants are used . Maintenance of anaerobic conditions of silage by compression to remove air they should be chopped to improve compaction [7]. Water soluble hydrocarbons are included for preservatives. Sugar rich sugarcane molasses are added to improve lactic acid production. Fermentation characteristics such as PH, ammonia nitrogen and fermentation end products are normally used to evaluate silage fermentation. Water Hyacinth has low lignin content (10%), high cellulose (20%) and high level of hemicelluloses (33%) [8]. The cellulose and hemicelluloses are easily converted to fermentable sugar thus resulting in enormous amount of utilizable biomass for biofuel industry.The main constraints are cost of production, engineering cost, infrastructure, installation, lack of experts etc. Ashutosh Deshpande [9] assessed the socio-economic factors affecting household waste generation and recycling behavior in Chennai: A survey-based study in 2024. Ahmad Hamdan [10] in 2024 studied AI in renewable energy: A review of predictive maintenance and energy optimization. In the same year Bhuiyan [11]Rana stated the Application of Linear Programming in Employee Allocation as a Case Study in Emerging Economy, Sundas Matloob [12] described the systematic review for the Management of methane emission in coal mines using artificial neural networks. Jamuna et al., modeled a Regression model for the people working in fire work industry-Virudhunagar district [13]. In 2021,

[14] studied the problems undergone in Semi Urban Areas as an Empirical Statistical Study. Local area studies and statistical survey in Nagapattinam District has been conducted and analyzed [15]. Some more regional studies like Perspective of people in Nagapattinam District has been reviewed [16]. Use of Mathematical analysis using the Ternary Cubic Diophantine equations is studied in [17]. Few another real time problems and analysis is reviewed in[18]. Review on transportation scheduling problem is clearly explained in[19]. Problems faced by common people in Nagapattinam District and A statistical analysis is carried out in [20]. In 2025, Jamuna analyzed Fuzzy Multi Criteria Group Decision Making With Vikor for Safe Disposal of Commercial Fish Waste [21]. In the same year, Transportation Problem in efficiency of Transport Hubs with Special Reference to Tamilnadu is evaluated [22]. some studies and different patterns of equations to solve real time problem is derived on solving Cubic Equation [23]. Detailed studies is emphasized in Biomass for Energy Production and Interval Transportation Problem to Minimize Transportation Cost [24]. Modelling and Optimising the Transhipment Problem of Nagapattinam Municipality Solid Waste Management is done in [25]. Jamuna et al., have done micro plastic pollution analysis using differential equations and computational models [26].

The whole process of conversion of the water Hyacinth to useful energy production is modeled below in figure 2.

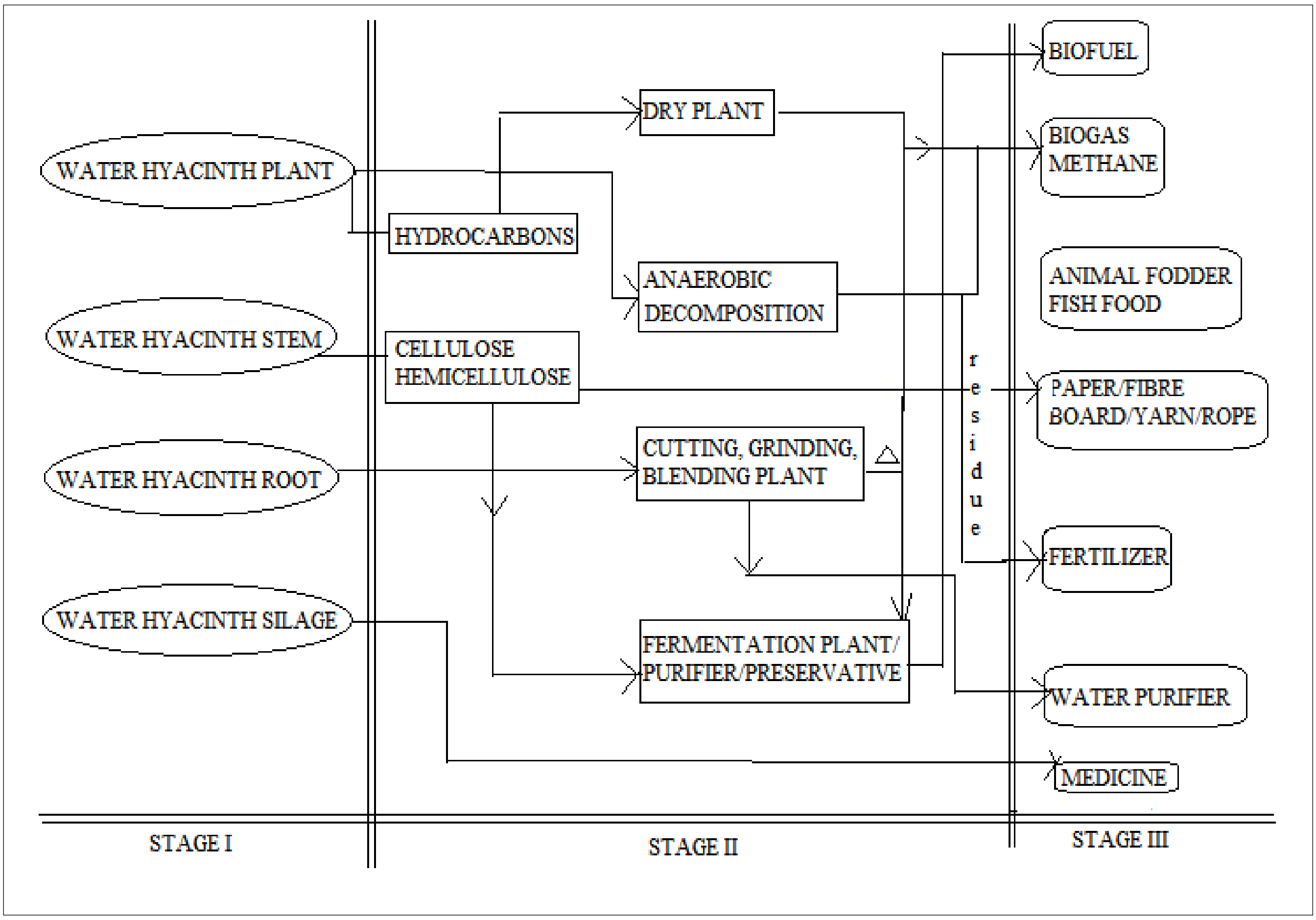

Figure 2 Different stages involved in converting Water Hyacinth to Biomass

6. Multi Objective Linear Programming:

MOLP is a type of mathematical optimization which contains more than one objective that is to be optimized. The decision variables are subject to a set of linear inequalities or equations.

Mathematically it is given by,

Optimize $Z_k = \sum_{j=1}^{n} c_{kj}\, x_j \,, k = 1,2,\dots m$

Subject to the constraints

$$\sum_{i=1}^{n} a_{ij}x_j \leq b_i\ , i = 1,2, \dots$$

$$x_j \geq 0, j = 1,2, \dots n$$

6.1. Notations used

- Z_k : represents different objective functions
- x_j : Decision variables
- C_{kj} : coefficient associated with each objective
- a_{ij} : constraint coefficients
- b_i : constraint limits

Due to its fast growth, *Eichhornia crassipes* serves as an excellent biomass source. One hectare of Water Hyacinth can produce 70,000 cubic meters of biogas, comprising approximately 70% methane and 30% carbondioxide.

6.2. Define the variables

$r_i$represents the type of raw material. Raw material may denote the water hyacinth plant asa whole, stem of Water Hyacinth, leaves of Water Hyacinth, root of Water Hyacinth as shown in stage I. $(i = 1,2,3 \dots)$

$g_i$represents the type of finished goods produced from the raw material r_i. The finished product may be biofuel, biomass, methane, animal fodder, fertilizer or water purifier as described in stage III. $(i = 1,2,3 \dots)$

$p_i$represents the type of processing plant constructed for the production of finished goods $g_i$from the raw material r_i. The type of processing plants may denote drying plant, anaerobic decomposition plant, cutting, crushing, blending plant, fermentation plant etc. as shown in stage II. $(i = 1,2,3 \dots)$

C_{r_i} represents the cost of generating raw material $r_i$to the plant . $(i = 1,2,3 \dots)$
Q_{r_i} represents the quantity of the raw material available. $(i = 1,2,3 \dots)$
T_{r_i}represents the transportation cost of one unit mass of raw material to the firm. $(i = 1,2,3 \dots)$
$CapT_{r_i}$represents the transportation capacity of the raw material r_i. $(i = 1,2,3 \dots)$
$PC_{r_ip_i}$ represents the processing cost of unit mass of raw material r_i in the plantp_i. $(i = 1,2,3 \dots)$
$T_{r_ip_i}$ represents the transportation cost of raw material r_i to the plant p_i. $(i = 1,2,3 \dots)$
$T_{p_ig_i}$ represents the transportation cost of finished goods $g_i$from the plant p_i to the market.
IC_{p_i} represents the capital amount or initial cost required for setting of processing plants p_i
LC_{r_i} be the labour cost involved in hand≤ling the raw material r_i
LC_{p_i} be the labour cost involved in the processing plants.
LC_{g_i} be the labour cost involved in handling (packing) the finished goods.
D_{g_i} be the demand of finished goods.
Cap_{p_i} represents the capacity of raw material that can be processed in the plant p_i
M_{g_i} represents the marketing cost of the finished goods in the market.
Next, Let us define the decision variables.
x_{r_i}denotes the quantity of raw material r_i in the stage I
$y_{r_ip_i}$ denotes the quantity of processed material in the second stage.
$z_{r_ip_ig_i}$ denote the quantity of finished goods $g_i$from the raw material r_i by the processing plant p_i

6.3. Objective is to minimize the total operation cost.

6.3.1. Cost of initial set up/infrastructure/ capital cost:

$$\min Z_1 = \sum_i IC_{p_i}$$

6.3.2. Cost of supplying raw material:

$$\min Z_2 = \sum_i C_{r_i} x_{r_i}$$

6.3.3. Transportation cost:

$$\min Z_3 = \sum_i T_{r_i} x_{r_i} + \sum_i T_{r_i p_i} y_{r_i p_i} + \sum_i T_{p_i g_i} z_{r_i p_i g_i}$$

6.3.4. Processing cost:

$$\min Z_4 = \sum_i PC_{r_i p_i} y_{r_i p_i}$$

6.3.5. Labour cost:

$$\min Z_5 = \sum_i LC_{r_i} x_{r_i} + \sum_i LC_{p_i} y_{r_i p_i} + \sum_i LC_{g_i} z_{r_i p_i g_i}$$

6.3.6. Marketing cost:

$$\min Z_6 = \sum_i M_{g_i} z_{r_i p_i g_i}$$

The objective function can be written as $\min z = \sum_{i=1}^{6} Z_i(x, y, z)$

Subject to the constraints

The quantity processed in the processing plant in stage II must not exceed the quantity of total raw material available in stage I. Similarly the quantity of the finished goods should not exceed the quantity in stage I and II.

$$x_{r_i} \geq y_{r_i p_i}$$

$$x_{r_i} \geq z_{r_i p_i g_i}$$

$$y_{r_i p_i} \geq z_{r_i p_i g_i}$$

The quantity of raw material in stage I should balance the total demand and availability.

$$D_{g_i} \leq x_{r_i} \leq Q_{r_i}$$

All decision variables are non-negative constraints.

$$x_{r_i} \geq 0$$

$$y_{r_i p_i} \geq 0$$

$$z_{r_i p_i g_i} \geq 0$$

This problem can be solved using LINDO (Linear Interactive and Discrete Optimizer package)

Convert the Multi objective into a single objective function using Weighted Sum Method (WSM) by assigning weights to all the objectives. [8]

Weighted Sum Method: Let m be the number of objective function.

$Z_1, Z_2, \ldots, Z_m betheindividualobjectivefunction$

$$Z = w_1 Z_1 + w_2 Z_2 + \dots + w_m Z_m$$

Where,

Z_i : individual objective functions

w_i :non- negative weights ($w_i \geq 0$)

$\sum w_i$ = normalization condition

7. Conclusion

Multi-Objective Linear Programming (MOLP) has been used as an efficient decision-making tool in this study, allowing the simultaneous optimization of multiple conflicting objectives, such as cost reduction, biomass yield maximization, and environmental sustainability. Although water hyacinth is frequently regarded as an invasive species, it has significant potential as a biomass resource, but optimizing its utilization requires a well-structured approach that balances economic, environmental, and operational factors. Complex real-world problems related to water hyacinth biomass production can be methodically examined and effectively resolved by utilizing mathematical modeling. The MOLP framework ensures that resource usage is both economically feasible and sustainable by offering decision-makers adaptable and ideal alternatives. Therefore, in waste-to-energy applications, mathematical optimization not only makes problem-solving easier but also improves the practical deployment of environmentally friendly solutions, opening the door to a sustainable future.

Compliance with ethical standards

Disclosure of conflict of interest

No Conflict of interest.

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