Global Journal of Researches in Engineering: G
Industrial Engineering
Volume 15 Issue 2 Version1.0 Year 2015
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN:2249-4596 Print ISSN: 0975-5861

# Linear Programming Model to Optimize Water Supply and Cropping Area for Irrigation: A Case Study for Kalihati

By Hasan Symum & Mohammad F Ahmed

*Florida State University, United States*

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*GJRE-G Classification:* *FOR Code: 290502p*

# Linear Programming Model to Optimize Water Supply and Cropping Area for Irrigation: A Case Study for Kalihati

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## I. Introduction

Economy of Bangladesh is largely dependent of agriculture and the total yields in agriculture is largely depends on irrigation water and rainwater. The average annual rainfall is lowest in the northwest part and highest in the northwest part. In the post-monsoon (October -November) and winter period (December - February) only 10 percent of the annual rainfall is available (WB, 2000). Rainfall is extremely unreliable in the subsequent pre-monsoon period (March - May). On an average there is about 10 percent of the annual rainfall in this period (WB, 2000). [1]. Water is very scarce in the south and northwest region of Bangladesh during the winter. [2] In order to plan the water supply distribution for irrigation, in relation to the production level and to the water needs, the factors that are necessary are seasonal and monthly needs of water supply, crop production and crop selection.

In addition to water supply facility, availability of fertilizer also plays a great role for on time production of seasonal crops.The demand is based on the type of area of cultivation, type of crops and growth rate.

There are different types of irrigation project that have been undertaken for proper irrigation management which includes ground water irrigation, surface water irrigation through public and private ventures. But due to scarcity of resources, it is found that such projects cannot always manage to satisfy farmer needs for proper yield. That is why farmers often face shortage of water and in many cases they use empirical way to maximize profit.

Different crops have different cropping cycle. These cycles are distributed throughout the year with overlapping periods. A particular land can be used for a particular crop whereas others can be used for two or three crops in succession. This leads to multiple choices available to select from for crop area selection. Each choice have different impact on the producer's net income. In order to find the best possible combination for maximum net income, cropping pattern and crop area allocation should be brought into consideration.

So there is scope for improvement of the situation of the farmers by distribution of water resource for each areaand land allotment for particular crop through the help of optimization tool. This optimization problem can be represented bya profit maximization function. The function is the difference between gross income and production cost subject to land availability, water supply, cropping pattern, market demand and other specific restrictions.[3,6]

In this paper, the location that had been selected for evaluating and formulating the model is KalihatiUpazilla, Tangail, Bangladesh.

## II. Mathematical Model

The objective is specified as net profit maximization equation as a function of cropping area based on cropping pattern and irrigation water supply. Net profit is the difference of gross income and production cost.

$$Net\ income = Gross\ income - Production\ cost$$

Gross income can be expressed as follows

$$G_I = \sum_{i=1}^{n} P_i X_i Y_i \quad (1)$$

Where,

$G_I = Gross\ income, BDT$

$P_i = Sale\ price\ of\ crop\ i, BDT/kg$

$X_i = Cropped\ area\ of\ crop\ i, ha$

$Y_i = Production\ rate\ of\ crop\ i, kg/ha$

*Author α σ : Department of Industrial & Manufacturing Engineering Florida State University, Tallahassee, FL 32310, USA.*
*e-mail: hs13b@my.fsu.edu*

$i = an\ integer\ representing\ each\ crop$
$(1, 2, 3 \ldots \ldots \ldots n)$

Production cost is divided into two components. One is for fixed cost related to each crop and the other one is variable cost proportional to irrigation depth. Fixed cost excludes irrigation cost. It includes labor, fertilizer, seeds, maintenance cost etc.

$$Production\ cost = Fixed\ cost + Variable\ cost$$

$$PC = \sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} C_w W_i X_i \qquad (2)$$

$PC = Total\ Production\ Cost, BDT$

$C_i = Fixed\ roduction\ cost\ of\ crop\ i, \frac{BDT}{ha}$

$C_w = Water\ cost\ for\ irrigation, \frac{BDT}{mmha}$

$W_i = Irrigation\ depth\ for\ crop\ i, mm$

The objective function can be expressed from equation (1) as follows

$$Maximize, Z = \sum_{i=1}^{n} P_i X_i Y_i - \left[\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} C_w W_i X_i\right] \qquad (3)$$

Where,

$Z = Net\ income, BDT$

This maximization functions is restricted by some constraint equations pertaining to total water supply availability, maximum crop area availability, irrigation depth range, seasonal and market demand restrictions.

Total water supply availability constraint

$$\sum_{i=1}^{n} W_i X_i \leq V_w \qquad (4)$$

Where,

$V_w = Annual\ irrigation\ water\ volume, mmha$

Maximum crop area availability constraint

$$\sum_{i=1}^{n} X_i \leq A_m \qquad (5)$$

Where,

$A_m = Area\ available\ for\ month\ m, ha$

Irrigation depth constraint has upper and lower bound. Too low irrigation water depth can cause the production to fall drastically and too much water depth can also flood the land which in turn again drops the crop productivity. Valid range for this irrigation depth were collected from Agricultural Specialist.

Irrigation depth constraint

$$W_{imin} \leq W_i \leq W_{imax} \qquad (6)$$

Where,

$W_{imin} = Minimum\ water\ depth\ required, mm$

$W_{imax} = Maximum\ water\ depth, mm$

Different crops have varied monthly basis demand pattern which depends on seasonal and market requirements. Some crops may also have location restriction for high or low land cultivation. These restrictions can be addressed as follows

$$X_i \leq B_i \qquad (7)$$

Where,

$B_i = Demand\ for\ crop\ i, ha$

Non-negativity constraint

$$X_i \geq 0 \qquad (8)$$

## III. Application of the Model: A Case Study at Kalihati

The model was applied to KalihatiUpazilla Irrigation System which is located at Kalihati, Tangail, Bangladesh. The required data was collected from "Monitoring Report for the Agriculture Year 2012-2013" which is published by Department of Agricultural Extension, Bangladesh.

For application of the model, the crops that were selected are the most traditional ones in the stated region. Also, in order to keep the model simple, not all the crops were included in the study as some of them had very little land allocation requirements. The selected crops are Aman(Transplanting), Aus, Aman(Broadcast), Boro Potato, Wheat, Mustard seeds, Jute, Onion and Garlic of which first four fall into rice category. These crops have different cropping cycle throughout the year which is summarized in Table 1.[4]

The production rate of crops ($Y_i$) were collected from the report as well. The selling price ($P_i$) were collected from online database of Department of Agricultural Marketing, Ministry of Agriculture, Government of the People's Republic of Bangladesh.[5] These data are stated in Table 2.

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*Table 1 :* Cropping calendar for Kalihati Irrigation Project

| Month | Crops | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T-Aman | B-Aman | Boro | Aus | Potato | Mustard seeds | Wheat | Jute | Garlic | Onion |
| Jan | | | √ | | | √ | √ | | √ | √ |
| Feb | | | √ | | | √ | √ | | √ | √ |
| Mar | | | √ | | | √ | √ | | √ | √ |
| Apr | | | √ | | | | | √ | √ | |
| May | | | √ | | | | | √ | | |
| Jun | | | | √ | | | | √ | | |
| Jul | | √ | | √ | | | | √ | | |
| Aug | √ | √ | | √ | | | | √ | | |
| Sep | √ | √ | | √ | √ | | | | | |
| Oct | √ | √ | | | √ | | | | √ | |
| Nov | √ | √ | | | √ | | √ | | √ | |
| Dec | | | | | | √ | √ | | √ | √ |

*Table 2 :* Production rate and selling price of different crops

| | Crops | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T-Aman | B-Aman | Boro | Aus | Potato | Mustard seeds | Wheat | Jute | Garlic | Onion |
| Production Rate, $Y_i$ (kg/ha) | 1980 | 1666 | 4033 | 1600 | 12450 | 1063 | 2735 | 3670 | 7178 | 9155 |
| Selling Price, $P_i$ (BDT/kg) | 32 | 33 | 38 | 43 | 12 | 45 | 23 | 36 | 45 | 19 |

The water depth requirements as well as production cost ($C_i$) were collected from the Monitoring report. The cost of irrigation ($C_w$) was acquired from Irrigation Institutions of Bangladesh: Some Lessons.[2] The cost of irrigation is 8.56 BDT/mmha. These data are represented in Table 3.

The water volume capacity ($V_w$) for irrigation was calculated and found to be 126798372 mmha. The data for this calculation are provided in Table 4.The Data were taken from Irrigation "Manual for Farmer and Monitoring report for the agricultural year 2012-13". The table shows the different types of water pump and their maximum irrigation capacity. Pumps can run 12 hours a day due to Electricity problem and maintenance of the water pump. Annual volume water supply for the KalihatiUpazilaIrrigation project is 1.2679837e+12 Liter or 1267898372mmha.

*Table 3 :* Water depth limits and Production costs for different crops[7,8]

| | Crops | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T-Aman | B-Aman | Boro | Aus | Potato | Mustard seeds | Wheat | Jute | Garlic | Onion |
| Maximum depth, $W_{imax}$ (mm) | 600 | 200 | 1500 | 860 | 220 | 100 | 200 | 50 | 150 | 120 |
| Minimum depth, $W_{imin}$ (mm) | 550 | 60 | 1300 | 650 | 180 | 10 | 150 | 10 | 100 | 100 |
| Production Cost, $C_i$ (BDT/ha) | 37560 | 30250 | 70510 | 25620 | 64680 | 41950 | 58628 | 50000 | 68210 | 40330 |

*Table 4 :* Water volume calculation for the observed year[2,9]

| Type | Number | Capacity (Lt/s) | Total (Lt/s) |
|---|---|---|---|
| Deep Tube well | 59 | 56.64 | 3341.76 |
| Shallow Tube well | 5327 | 14.16 | 75430.20 |
| Power Pumps | 58 | 28.32 | 1642.56 |
| | | Total | 80415.00 |

*The objective function for this case study can be extended after calculating all the available data*

$$Maximize, Z = 25800X_1 + 24728X_2 + 82744X_3 + 43180X_4 + 84720X_5 + 5885X_6 + 4277X_7 + 82120X_8 + 254800X_9 + 133615X_{10} - 8.56(W_1X_1 + W_2X_2 + W_3X_3 + W_4X_4 + W_5X_5 + W_6X_6 + W_7X_7 + W_8X_8 + W_9X_9 + W_{10}X_{10})$$

The restrictions for the cropped area are following

a) *Constraints for water supply availability*

$$W_1X_1 + W_2X_2 + W_3X_3 + W_4X_4 + W_5X_5 + W_6X_6 + W_7X_7 + W_8X_8 + W_9X_9 + W_{10}X_{10} \leq 126798372\ mmha$$

b) *Constraint for maximum crop area availability*

$$X_3 + X_6 + X_7 + X_9 + X_{10} \leq 17750\ ha$$
$$X_3 + X_7 + X_8 + X_9 + X_{10} \leq 17750\ ha$$
$$X_3 + X_8 + X_9 \leq 17750\ ha$$
$$X_3 + X_8 \leq 17750\ ha$$
$$X_4 + X_8 \leq 17750\ ha$$
$$X_2 + X_4 + X_8 \leq 17750\ ha$$
$$X_1 + X_2 + X_4 + X_8 \leq 17750\ ha$$
$$X_1 + X_2 + X_4 + X_5 \leq 17750\ ha$$
$$X_1 + X_2 + X_5 + X_9 \leq 17750\ ha$$
$$X_1 + X_2 + X_5 + X_6 + X_7 + X_9 \leq 17750\ ha$$
$$X_6 + X_7 + X_9 + X_{10} \leq 17750\ ha$$

c) *Constraint for irrigation depth*

$$550 \leq W_1 \leq 600$$
$$60 \leq W_2 \leq 200$$

$$1300 \le W_3 \le 1500$$
$$650 \le W_4 \le 860$$
$$180 \le W_5 \le 220$$
$$10 \le W_6 \le 100$$
$$150 \le W_7 \le 200$$
$$10 \le W_8 \le 50$$
$$100 \le W_9 \le 150$$
$$100 \le W_{10} \le 120$$

d) *Particular high land requirement for mustard seeds*

$$X_6 \le 1860\ ha$$

e) *Market demand constraint for*

T-Aman has a minimum requirement of 3000 hector due to market demand

$$X_1 \ge 3000\ ha$$

B-Aman also has a minimum requirement of 1600 hector due to market demand

$$X_2 \ge 1600\ ha$$

f) *Particular land constraint for Aus and Potato*

Aus and Potato can be cropped in a particular area of land which have the following limit

$$X_4 \le 1850\ ha$$
$$X_5 \le 400\ ha$$

g) *Local demand and available land constraint for Garlic and Onion*

Both of them have limits for available land due their particular cropping procedure. But considering the need of local markets they have minimum bounds

$$50 \le X_9 \le 100\ ha$$
$$60 \le X_9 \le 120\ ha$$

h) *Non-negativity constraints*

$$X_6 \ge 0\ ha$$
$$X_7 \ge 0\ ha$$
$$X_8 \ge 0\ ha$$

## IV. Results and Discussion

After carrying out the study for irrigation project at Kalihati with yearly water availability of 126798372 mmha and land availability of 17750 ha, optimum crop planning and recommended values for water depth for different crops were identified using the maximization function while satisfying maximum and minimum crop area requirements. The problem was solved using Lingo, an optimization modelling software. The results of the model obtained from the software after going through 34 iterations and 0.21s elapsed time are shown in Table 5. The T-Aman crop was indicated a recommended area for cropping of 3000 ha associated with its lowest bound. B-Aman represented an area of 10920 ha with 150 mm water depth requirements. While Boro and Aus had greater impact on objective function having high net volume coefficient, only Boro seemed to achieve highest cropped area (i.e. 15670 ha). This is due to the land allocation limit for Aus crop which is 1850 ha. As Potato and Mustard seeds have upper bounds they were found to have reached that bound with minimum water depth requirements. Even though Wheat and Jute had no upper bounds, Wheat had no area allocated for production whereas Jute had 1980 ha allocation. Such scenario can also be attributed to the difference in their net income factor in maximization function. Garlic and Onion had good productivity but production were limited to their restriction for availability of land. The net income worth for this project was 1,856,910,000BDT.

*Table 5 :* Result obtained by optimizing the objective function

| Crops | Area(ha) | Water depth(mm) | Sowing time |
|---|---|---|---|
| T-Aman | 3000 | 550 | August |
| B-Aman | 10920 | 150 | July |
| Boro | 15670 | 1300 | January |
| Aus | 1850 | 650 | June |
| Potato | 400 | 180 | September |
| Mustard seeds | 1860 | 10 | December |
| Wheat | 0 | - | - |
| Jute | 1980 | 10 | April |
| Garlic | 100 | 100 | October |
| Onion | 120 | 120 | December |

## V. Conclusion

The model applied to the studied area found to be suitable for irrigation and cultivation decision making which gave optimum result for required variables such as irrigation water depth and cropping area allocation. The land area limitation and constraints of water supply became effective restriction for the model. The local market demand also significant impact in setting the production requirements.

## VI. Acknowledgment

The author would like tothank the course teacher Dr. Abhishek Kumar Shrivastava for prompting them to carry out this project as a part of their course.

The author also like to express their gratitude towards Department of Agricultural Extension, KalihatiUpazilla, Tangail, Banladesh for providing the required cropping cycle, production cost and other relevant data.

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