

**WATER MANAGEMENT IN BANGLADESH AGRICULTURE:
OPTIMAL USE AND INVESTMENT POLICIES FOR
ADAPTATION TO CLIMATE CHANGE**

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Statement of the problem

- The impacts of climate change on water requirement for agriculture are high on the research agenda worldwide.
- In Bangladesh, the effects of climate change on water resources will be severe (IPCC, 2007).
- The National Adaptation Programme of Action (NAPA) highlights water related impacts of climate change to be amongst the most critical for Bangladesh, particularly in relation to riverine and coastal flooding, but also in relation to increased winter droughts in some areas (MOEF, 2005).

Trend of Rainfall Pattern and Status of Irrigation Water

- The annual mean rainfall has been increasing and flooding is occurring once in every 4 to 5 years in the country (MOEF, 2008).
- Winter months, i.e., November to March, are very dry in Bangladesh due to low rainfall whereas about 95% of annual rainfall occurs during April to October.
- The annual renewable water of Bangladesh from all sources is 1211 cubic kilometer and out of this about 21 cubic kilometer from groundwater (FAO, 2000).
- Annual irrigation water requirement in the country is about 19 cubic kilometer. Water withdrawal is 76 cubic kilometer that is only 6 percent renewable water is being withdrawn for agriculture.
- Both surface water and groundwater are used for irrigation where 80 per cent of total irrigated area (4,787,000 hectare) is under groundwater irrigation.

Table 1. Projected Climate Change Scenarios for Bangladesh

| Year | Temperature increase (c ⁰) | | Precipitation fluctuation compared to 1990 (%) | |
|------|--|--------|--|--------|
| | Monsoon | Winter | Monsoon | winter |
| 2030 | +0.8 | +1.1 | +6 | -2 |
| 2050 | +1.1 | +1.6 | +8 | -5 |
| 2100 | +1.9 | +2.7 | +12 | -10 |

Source: Costal Development Strategy 2006, Water Resources Planning Organization, Ministry of Water resources, Bangladesh

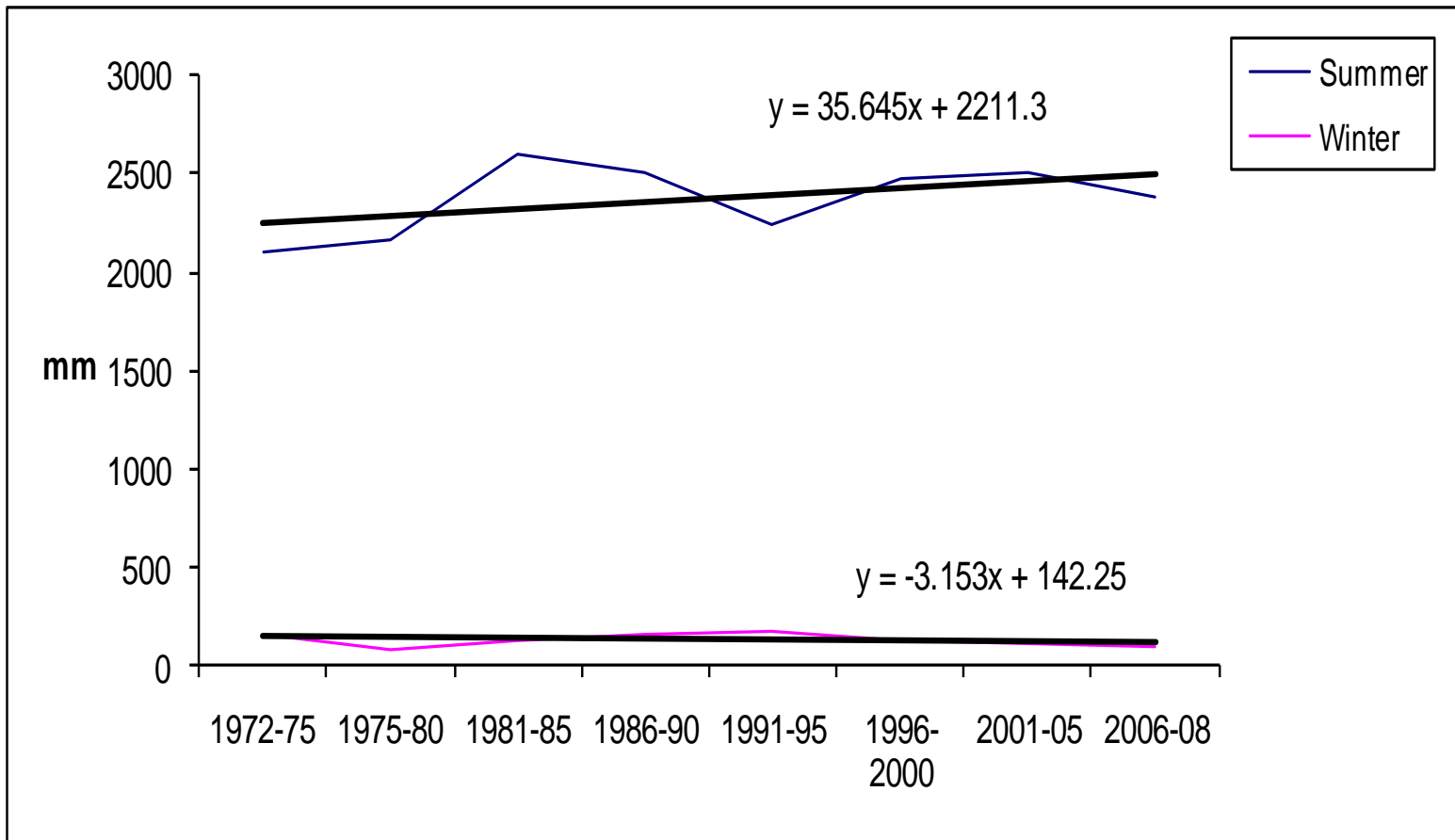
Scarcity of irrigation water

- Irrigation is a prerequisite for agricultural cultivation during the dry season (Asiatic Society of Bangladesh 2006). .
- Boro the dry season rice covers most of the rice production in Bangladesh.
- The development of irrigation infrastructure has contributed to the expansion of boro rice areas.
- Water scarcity is becoming a serious problem for agricultural production due to lower rainfall during the dry season.

Table 2. Trends in rice area, production, and yield in different seasons, 1969–2008

| Year | HYVBoro rice (winter) | | | HYVAus rice (pre-monsoon) | | | HYVAman rice (monsoon) | | |
|---------|-----------------------|-----------------------|--------------|---------------------------|-----------------------|--------------|------------------------|-----------------------|--------------|
| | Area (000 ha) | Production (000 tons) | Yield (t/ha) | Area (000 ha) | Production (000 tons) | Yield (t/ha) | Area (000 ha) | Production (000 tons) | Yield (t/ha) |
| 1969–71 | 894 | 2,853 | 3.19 | 3,242 | 4,254 | 1.31 | 5,860 | 9,866 | 1.68 |
| 1979–81 | 1,127 | 3,648 | 3.23 | 3,127 | 4,692 | 1.50 | 5,937 | 11,348 | 1.91 |
| 1989–91 | 2,183 | 9,111 | 4.17 | 2,348 | 3,796 | 1.62 | 5,689 | 13,012 | 2.29 |
| 1999–01 | 3,646 | 16,750 | 4.59 | 1,367 | 2,634 | 1.93 | 5,740 | 15,202 | 2.65 |
| 2006–08 | 4,315 | 23,346 | 5.41 | 952 | 2,382 | 2.50 | 5,367 | 15,657 | 2.92 |

Table 4. Trends in Summer and Winter Rainfall



Rationale for optimal Water Management under Climatic Variability and Change

- The population of the country is about 162 million in 2009 and is projected to be double in 2050 (FAO, 2009).
- Demand for water will increase with the rising population for rice production.
- The water scarcity problem in Bangladesh becomes worse due to expansion and diversification of agricultural crops while maintaining self sufficiency in food grain production.
- To meet existing and upcoming future demands for irrigation water for the increasing population, water use for irrigation needs to be analyzed for making decisions on optimal dam release and expected change in rainfall patterns.
- In order to ensure the maximum productivity of irrigation water considering the scarcity of water, new water use policies and existing policies should be evaluated by applying economic tools to ensure the maximum social return from irrigation water.

Table 5. Summary of Mathematical Tools Application in Water Management

| Reference | Objective | Mathematical Tools | Issue Addressed |
|---|---|--|---|
| Adamson et al. (2009); Connor et al. (2009); Griffith et al. (2009); Jeuland (2009) | Irrigation and river basin management with climate change | Water balance model; stochastic programming; Monte Carlo Simulation | A state contingent representation of production under uncertainty, reduced water allocation levels on the irrigation sector; water trading plans; sensitivity and adaptability of water resource; optimal planning for hydroelectricity generation under climate change |
| Nelson et al. (2009); Adamson et al. (2007); Block et al. (2008), Vicuna (2007) | Adaptation to climate change and decision under risk | IMPACT model; linear and nonlinear programming; dynamic climate module, stochastic dynamic programming | Food security and investment with the modeling of crop growth; decision framework incorporating risk and uncertainty for policy analysis; prospective irrigation and infrastructure investment strategies, irrigation and hydropower generation considering inter temporal allocation of surface water. |

Table 6. studies on climate change and water resources in Bangladesh

| Reference | Objective | Mathematical Tools | Issue Addressed |
|--|--|--|---|
| Climate change cell, 2009; World Bank, 2010 | Economic modeling for adaptation to climate change; Estimate climate change adaptation costs for developing countries | Cost benefit analysis; General Circulation model, integer, programming | Development of physical adaptation model and development of economic model for water management infrastructures in the coastal zone; The cost of developing countries to adapt to climate change between 2010 and 2050 is estimated at US\$70 billion to US\$100 billion a year at 2005 prices. This amounts to about “only” 0.2% of the projected GDP of all developing countries in the current decade |

Objective of the Study

To make decision on annual release of water for rice production dependent on water availability considering climate change in terms of changing pattern of precipitation for which the present value of allocation is maximized.

Sources and collection of data

- Data (historical data on climatic factors, water availability, surface and groundwater irrigation, population and rice production) are being collected from the following organizations:
- Bangladesh Water Development Board (BWDB)
- Bangladesh Agricultural Development Corporation (BADC)
- Bangladesh Meteorological Department (BMD)
- Bangladesh Bureau of Statistics (BBS)
- Institute of Water Modeling (IWM)
- International Food Policy Research Institute (IFPRI)
- Food and Agricultural Organization (FAO)
- International Rice Research Institute (IRRI)
- International Water Management Institute (IWMI)
- World Resource Institute (WRI)
- World bank (WB)
- Web and internet resources

Analytical techniques

A stochastic finite stage dynamic programming model is developed to determine the optimal annual application of irrigation water over a 3-year planning horizon given uncertain water availability.

Model formulation

- Mathematical programming has long been recognized as a vital modeling approach to solve optimizations problems.
- Linear programming (LP) was the first technique and developed during the Second World War for military planning.
- There are wide ranges of uses of LP in the planning of economic development and agricultural policies for maximizing profit or minimizing costs with limited resources.
- Quadratic programming and chance constrained programming are successfully used in many problems in policy and resource management areas after introducing LP.
- These techniques overcome some of the LP limitations (i. e., additivity, proportionality, continuity and finiteness). But those mathematical programming were not enough when considering multistage decision problem of resource management.
- The theory of dynamic programming yields a systematic technique for formulating problems of this nature and for obtaining computational solutions (Bellman, 1961)

Contd.

- The applied problem of irrigation water management involves multistage decision making with stochastic event (rainfall).
- Social net return of rice production depends not only on the decision of irrigation water application but also on stochastic event.
- The optimal quantity of water to apply at each of 3-stages over 3-years planning horizon from 2012 to 2014 is determined.
- The state variable is amount of water available, rainfall is a random variable, affecting available water and water received by the crop.
- The stage return function of a stage would be the expected social net return.

Objective Function

- The objective function to be maximized is the sum of the expected discounted stage returns.
- The expected present value of social net returns is obtained from rice production in all the decision stages over the T years by applying irrigation water.

Objective Function, $Max_{u_t} Z = \sum_{t=1}^T \rho_t(j_t) \alpha^{t-1} \Pi_t + \alpha^T F(q_{T+1}) \dots\dots\dots(i)$

Subject to $q_{t+1} = q_t - u_t + r_t \dots\dots\dots(ii)$

Initial water stock level, $q_1 = \bar{q}_1 > 0 \dots\dots\dots(iii)$

Contd.

where,

$t = 1, 2, \dots, T$ years

$T =$ length of the planning horizon of 3 years

$\Pi_t =$ net social return,

$\rho_t(j_t) =$ probability distribution of rainfall,

$\alpha =$ the discount factor,

$F(q_{T+1}) =$ terminal value of irrigation water stock remaining at stage $T+1$

$W_t =$ irrigation water applied at the beginning of year t

$q_t =$ total amount of irrigation water available at the beginning of year t

$\bar{q}_1 =$ stock of surface water available at stage 1

$r_t =$ rainfall at year

$u_t =$ dam release at time t

Contd.

A linear demand function for rice is specified with price in period t

$$p_t = \eta + \varphi y_t \dots\dots\dots (iv)$$

$t = 1, 2, \dots\dots\dots T$

where,

- η and φ are parameters with $\varphi < 0$
- p_t = price of rice at the end of year t
- y_t = quantity of rice at the end of year t

Contd.

The consumer surplus for consumption(y_t) is given by the area under the inverse demand schedule.

$$CS\{y_t\} = \int_0^{y_t} (\eta + \phi y_t) dy_t - p_t y_t \dots\dots\dots(v)$$

p_t = price of rice at the end of year t

y_t = yield of rice at the end of year t

Quadratic production function of rice is:

$$y_t = A + \phi w_t + \epsilon w_t^2 \dots\dots\dots(vi)$$

where,

w_t = irrigation water applied at time t

$$w_t = u_t + r_t \dots\dots\dots(vii)$$

where,

r_t = rainfall during year t

Contd.

Expected net social return,

$$\begin{aligned}
 \prod_t &= \sum_{t=1}^T \sum_{j_t=1}^m \rho_t(j_t) \{CS(y_t)\} \\
 &= \sum_{t=1}^T \sum_{j_t=1}^m \rho_t(j_t) \left[\int \{ \eta + \phi(A + \phi w_t + \varepsilon w_t^2) \} dy_t \right] \\
 &= \sum_{t=1}^T \sum_{j_t=1}^m \rho_t(j_t) \left[\int \{ (\eta + \phi)(A + \phi w_t + \varepsilon w_t^2) \} \right] \\
 &= \sum_{t=1}^T \sum_{j_t=1}^m \rho_t(j_t) \left[\int \{ (\eta + \phi)(A + \phi(u_t + r_t^j) + \varepsilon(u_t + r_t^j)^2) \} \right] \quad \dots\dots(viii)
 \end{aligned}$$

The corresponding recursive equation for solving the problem is

$$V_t\{q_t\} = \max_{u_t} \left\{ \sum_{t=1}^3 \sum_{j_t=2}^4 \rho_t(j_t) \left[\int \{ (\eta - \phi)(A + \phi(u_t + r_t^j) + \varepsilon(u_t + r_t^j)^2) \} \right] + \alpha V_{t+1}\{q_t - u_t + r_t^j\} \right\} \dots\dots(ix)$$

(t = 3 to 1)

Subject to $\sum_{j_t=2}^4 \rho_t\{j_t\} = 1$ with $V_4(q_4) = 0$

A simple rice crop irrigation problem

Assume,

Planning horizon 2012-2014

Area of dam 1 hectare

Dam is full with 3 meter of water height

Social rate of discount 5.26 %

Rice water response function,
$$y_t = 3484.79 + 0.13w_t - 0.000016w_t^2 \dots \dots \dots (x)$$

(0.00) (0.02)

The yield of rice is 400 tons per 100 hectare

Table7: Rainfall probabilities

| <i>j</i> | Decision stage | | | | | |
|----------|----------------|---------|--------------|---------|--------------|---------|
| | 1 | | 2 | | 3 | |
| | $p_1\{j_1\}$ | r_1^j | $p_2\{j_2\}$ | r_2^j | $p_3\{j_3\}$ | r_3^j |
| 1 | 0.25 | 2 | 0.25 | 1 | 0.25 | 0 |
| 2 | 0.50 | 3 | 0.50 | 2 | 0.50 | 1 |
| 3 | 0.25 | 4 | 0.25 | 3 | 0.25 | 2 |

Table 8: Stochastic dynamic programming solution

| Stochastic dynamic programming solution | | | | | |
|---|-------|----------|---------|-------------------------------|---------------------------------|
| Problem ---CISF--- | | | | | |
| Problem parameters: | | | | | |
| No. Of decision stages = 3 | | | | | |
| Rate of discount (per cent) = 5.26 | | | | | |
| Stochastic Solution For Stage 3 | | | | | |
| State | | Decision | | Stage Return (million BDT) | Expected Value (million BDT) |
| No. | Level | No. | Release | | |
| 1 | L0 | 1 | R0 | 27.38 | 27.38 |
| 2 | L1 | 2 | R1 | 54.76 | 54.76 |
| 3 | L2 | 3 | R2 | 82.14 | 82.14 |
| 4 | L3 | 4 | R3 | 102.66 | 102.66 |
| Stochastic Solution for Stage 2 | | | | | |
| State | | Decision | | Stage Return | Expected Value |
| No. | Level | No. | Release | | |
| 1 | L0 | 1 | R0 | 26.46 | 78.49 |
| 2 | L1 | 2 | R1 | 52.92 | 104.95 |
| 3 | L2 | 3 | R2 | 79.37 | 131.40 |
| 4 | L3 | 3 | R2 | 79.37 | 155.78 |
| Stochastic Solution for Stage 1 | | | | | |
| State | | Decision | | Stage Return | Expected Value |
| No. | Level | No. | Release | | |
| 1 | L0 | 1 | R0 | 31.98 | 156.32 |
| 2 | L1 | 2 | R1 | 51.16 | 175.50 |
| 3 | L2 | 3 | R2 | 76.74 | 201.08 |
| 4 | L3 | 4 | R3 | 95.91 | 220.26 |

Conclusion

- In Bangladesh, rice covers major portion of agricultural production.
- Boro rice contributes a large share of rice production and that is exclusively depends on irrigation due to a dry season crop.
- Stochastic finite stage dynamic programming model showed the dam releases decisions considering possible range of rainfall patterns maximized the net social return from rice production.
- Climate change oriented irrigation water management should be the basic rice production strategy for Bangladesh and that can be recommended by the model findings.

Ongoing further steps

- Probability distribution of the stochastic events and linkages between the climate scenarios and the water resources system
- Cost benefit analysis for building dam under the given climate scenario and project alternatives for adaptation to climate change.

Thank You