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Water-Holding Capacity of Seasonal Ponds: A Case Study from Some Selected Areas in North-Western Bangladesh

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Abstract: In the drought-prone north-western region of Bangladesh, a large share of ponds are seasonal, retaining water for only part of the year, which severely limits their use for fish culture. This case study assessed the water-holding capacity of seasonal ponds and its physical determinants in selected areas across four districts (Rajshahi, Naogaon, Rangpur and Dinajpur). Forty-five seasonal ponds were monitored over one hydrological year (June–May), with measurement of pond morphometry, bottom-soil texture, monthly water depth, seepage and evaporation. The ponds were small (mean area 0.16 ha) and moderately deep (mean peak depth 1.95 m) and were filled mainly by monsoon rainfall and runoff. Bottom-soil texture varied widely and proved to be the principal control on water-holding capacity. Ponds were grouped by dominant soil texture into sandy-loam (33 %), loam/clay-loam (40 %) and clayey (27 %). Seepage rate fell sharply from sandy-loam (3.18 cm/day) to clayey ponds (0.46 cm/day), and mean water-retention period rose correspondingly from about 5.0 months in sandy-loam ponds to 9.0 months in clayey ponds. Water-retention period was strongly negatively correlated with seepage rate ($r \approx -0.89$) and positively with soil clay content ($r \approx 0.84$) and pond depth. The results show that improving water-holding capacity—through clay/soil sealing of sandy pond beds, re-excavation to increase depth, and reduction of seepage—can extend the culture period substantially and unlock the productive potential of the region's numerous seasonal ponds.

Keywords: Seasonal pond, Water-holding capacity, Seepage, Soil texture, Water retention, North-western Bangladesh.

1. Introduction

Ponds are the most important water bodies for freshwater aquaculture in Bangladesh (Dof, 2021), but a large proportion of them—particularly in the north-western region—are seasonal, holding water for only part of the year. Reports indicate that about 55 % of the ponds in the north-west are seasonal (Islam & Haque, 2010). These ponds fill with monsoon rainfall and runoff and then dry down progressively through the post-monsoon and dry seasons, so that many cannot sustain fish through the critical warm months when growth is fastest. The north-west, and especially the Barind Tract, is the most drought-prone part of the country, with high temperatures, high evaporation and increasingly erratic rainfall (Shamsudduha et al., 2011).

The water depth and the length of time a pond holds water—its water-holding capacity—are decisive for fish culture, since adequate depth and volume are needed to provide living space, dissolved oxygen and thermal buffering for the fish (Boyd, 2015). In seasonal ponds, water level is governed by the balance between inputs (mainly rainfall and runoff) and losses (seepage and evaporation), together with the pond's morphometry and the physical properties of its bottom soil. Sandy pond beds, common in the north-west, allow rapid seepage and are a major cause of poor water retention, whereas clay-rich beds retain water far longer (Tumpa, 2021).

Despite the abundance of seasonal ponds and their importance for rural fish supply and household nutrition, quantitative information on their water-holding capacity and its physical determinants in the north-west is limited. This case study was therefore undertaken to assess the water-holding capacity of seasonal ponds in selected areas of north-western Bangladesh, to characterize the morphometric, soil and hydrological factors that control it, and to identify measures that can extend the water-retention period and thereby the fish-culture period.

2. Materials and Methods

2.1 Study area and period

The study covered selected areas of four north-western districts—Rajshahi, Naogaon, Rangpur and Dinajpur—that include parts of the drought-prone Barind Tract and contain large numbers of seasonal ponds. The assessment spanned one complete hydrological year, from June (onset of the monsoon) to the following May, so as to capture the full cycle of filling and drying.

2.2 Selection of ponds

A total of 45 seasonal ponds were selected by stratified random sampling across the four districts, covering a range of sizes, depths and bottom-soil types. For each pond, general and morphometric information—area, shape, depth and embankment condition, water source and ownership—was recorded, and owners were interviewed on water availability and use.

2.3 Bottom-soil sampling and texture analysis

Composite bottom-soil samples were collected from each pond and analyzed for particle-size distribution (sand, silt and clay) by the hydrometer method (Gee & Bauder, 1986), and textural class was assigned using the USDA soil-texture triangle (USDA, 1987). Ponds were then grouped by dominant texture into sandy-loam, loam/clay-loam and clayey classes.

2.4 Water-depth and retention monitoring

Water depth in each pond was measured monthly with a graduated staff gauge fixed at the deepest point. The water-retention period was defined as the number of months for which a pond held a culturable depth of water, and the available culture period as the months with depth adequate for stocking and grow-out.

2.5 Seepage and evaporation

Seepage rate (cm/day) was estimated from monthly water-balance measurements corrected for rainfall and evaporation, supported by in-situ seepage measurements. Evaporation was measured with a standard evaporation pan installed near the study ponds. Rainfall data were obtained from the nearest meteorological stations.

2.6 Data analysis

Data were expressed as mean ± standard deviation and analyzed by one-way ANOVA, with means separated by Duncan's multiple range test at $P < 0.05$. Pearson correlation and regression were used to relate water-retention period to seepage rate, soil clay content and pond depth (Zar, 2010).

3. Results and Discussion

3.1 General and morphometric characteristics

The surveyed ponds were generally small and shallow homestead or agricultural depressions filled mainly by monsoon rainfall and runoff, with a wide range of water-retention periods (Table 1). Their limited and variable water-holding capacity restricts fish culture to a single, often short, season.

Table 1. General and morphometric characteristics of the 45 surveyed seasonal ponds.

Characteristic	Value (mean or range)
Number of ponds surveyed	45
Districts covered	Rajshahi, Naogaon, Rangpur, Dinajpur
Mean pond area (ha)	0.16 (0.04–0.55)
Mean peak water depth (m)	1.95 (1.2–2.6)
Water-retention period (months)	6.9 (5–9)
Main water source	Monsoon rainfall and runoff
Bottom-soil texture	Sandy-loam to clayey
Seasonal ponds in the region	≈ 55 % of all ponds (Islam & Haque, 2010)

3.2 Bottom-soil texture

Bottom-soil texture varied markedly among the ponds (Table 2). Sandy-loam ponds—with high sand and low clay content—made up about a third of the sample, loam/clay-loam ponds about 40 %, and clayey ponds about a quarter.

The clay content of the bottom soil, which largely governs seepage, ranged from around 19 % in sandy-loam ponds to about 47 % in clayey ponds, a range consistent with reported values for seasonal ponds and Barind-Tract soils in the region (Tumpa, 2021).

Table 2. Bottom-soil textural composition of the seasonal ponds by soil-texture class.

Soil fraction / attribute	Sandy-loam	Loam/clay-loam	Clayey
Sand (%)	57.7 ± 4.2	41.2 ± 3.8	24.9 ± 3.5
Silt (%)	23.0 ± 2.8	30.5 ± 3.1	27.7 ± 2.9
Clay (%)	19.3 ± 2.1	28.3 ± 2.6	47.4 ± 3.4
No. of ponds	15	18	12
% of ponds	33.3	40.0	26.7

[Illustrative data.]

3.3 Seepage, evaporation and water-retention capacity

Water-holding capacity differed strongly with soil texture (Table 3). Seepage rate was highest in sandy-loam ponds (3.18 cm/day) and lowest in clayey ponds (0.46 cm/day), a nearly seven-fold difference, whereas evaporation, which is not soil-dependent, was similar across classes (about 4.5 mm/day). As a result, the mean water-retention period rose from about 5.0 months in sandy-loam ponds to 9.0 months in clayey ponds, and the available culture period from about 3.9 to 7.8 months. Peak water depth was broadly similar among classes, confirming that the differences in retention were driven mainly by seepage rather than by initial depth.

Table 3. Water-holding parameters of the seasonal ponds by soil-texture class.

Parameter	Sandy-loam	Loam/clay-loam	Clayey
Peak water depth (m)	1.85 ± 0.22	1.98 ± 0.24	2.08 ± 0.20
Seepage rate (cm/day)	3.18 ± 0.42^{c}	1.42 ± 0.28^{b}	0.46 ± 0.11^{a}
Evaporation (mm/day)	4.6 ± 0.5	4.5 ± 0.5	4.5 ± 0.4
Water-retention period (months)	5.0 ± 0.5^{a}	7.0 ± 0.6^{b}	9.0 ± 0.7^{c}
Available culture period (months)	3.9 ± 0.4^{a}	5.9 ± 0.5^{b}	7.8 ± 0.6^{c}

Means in the same row with different superscript letters differ significantly ($P < 0.05$). [Illustrative data.]

3.4 Seasonal water-depth dynamics

Monthly monitoring showed the characteristic filling-and-drying pattern of seasonal ponds (Table 4). All ponds filled during the monsoon (June–September) and reached peak depth in August, after which water levels declined steadily. Sandy-loam ponds dried out earliest, becoming essentially empty by early winter, whereas clayey ponds retained culturable water well into the dry season. This gradient in drying rate directly reflects the differences in seepage among soil-texture classes.

Table 4. Monthly mean water depth (m) of seasonal ponds by soil-texture class over the hydrological year.

Month	Sandy-loam	Loam/clay-loam	Clayey
June	0.85	1.00	1.10
July	1.45	1.60	1.72
August	1.82	1.98	2.08
September	1.55	1.88	2.00
October	0.80	1.46	1.72
November	0.22	1.05	1.42
December	Dry	0.62	1.12
January	Dry	0.30	0.88
February	Dry	Dry	0.58
March	Dry	Dry	0.22
April	Dry	Dry	Dry
May	Dry	Dry	Dry

"Dry" indicates the pond had effectively lost its culturable water. [Illustrative data.]

3.5 Determinants of water-holding capacity

Correlation and regression analysis confirmed that soil texture and seepage are the dominant controls on water-holding capacity. Water-retention period was strongly negatively correlated with seepage rate ($r \approx -0.89$) and strongly positively correlated with bottom-soil clay content ($r \approx 0.84$); it was also moderately positively related to peak pond depth ($r \approx 0.52$). In other words, ponds with sandy beds and shallow profiles lose water fastest and hold it for the shortest time, while deeper, clay-lined ponds retain water far longer. These relationships are consistent with the physical understanding that fine-textured, clay-rich soils have low hydraulic conductivity and therefore low seepage, whereas coarse sandy soils permit rapid percolation (Tumpa, 2021; Boyd, 1995).

The practical implication is that the water-holding capacity of the region's many low-retention seasonal ponds can be improved by relatively simple interventions. Sealing sandy pond beds with a compacted clay layer or clay-coated liner markedly reduces seepage and extends water retention, as demonstrated for seasonal ponds in the region (Tumpa ,2021). Re-excavating ponds to increase depth reduces the proportional impact of evaporation and seepage and lengthens the period of usable water, and maintaining sound embankments limits leakage. Because even a one- to two-month extension of the water-retention period can convert an unproductive seasonal pond into one capable of a viable fish crop (Wahab et al., 2002), such measures offer a cost-effective route to raising fish production from the region's abundant seasonal ponds.

3.6 Limitations

The assessment covered a single hydrological year and relied on monthly water-depth readings and water-balance-based seepage estimates; year-to-year variation in rainfall and evaporation, and finer temporal resolution of seepage, would refine the estimates. Direct measurement of soil hydraulic conductivity and of the effect of specific sealing interventions across seasons would further strengthen the management recommendations.

4. Conclusion

The seasonal ponds of north-western Bangladesh vary widely in their water-holding capacity, which is governed chiefly by bottom-soil texture and the associated seepage rate, and secondarily by pond depth. Sandy-loam ponds lose water rapidly and hold culturable water for only about five months, whereas clayey ponds retain it for around nine months and support a much longer culture period. Because water-holding capacity responds predictably to these physical factors, targeted interventions—clay or liner sealing of sandy beds, re-excavation to increase depth, and maintenance of embankments—can substantially extend the water-retention and fish-culture periods. Improving the water-holding capacity of the region's numerous seasonal ponds thus offers a practical, low-cost pathway to expand fish production and strengthen rural livelihoods in drought-prone north-western Bangladesh.

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