# CE718: WATER RESOURCES SYSTEMS ANALYSIS

***(Group number: 4)***

***Group members:***

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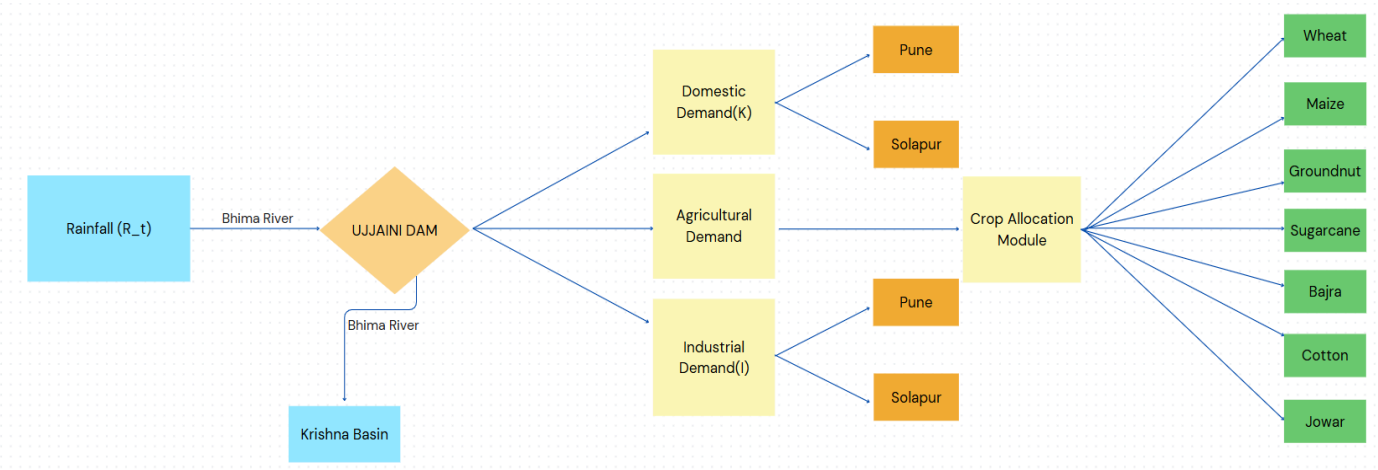
## 1. Network Diagram

The network diagram developed for the **Ujjani Dam** system includes the following




- **Reservoir**: Ujjani Dam (on Bhima River)
- **Water Users**:
    - Crop cultivation (mainly wheat, maize, groundnut, sugarcane, bajra, cotton, jowar)
    - Urban Users (e.g., Solapur City, Pune)
    - Industrial uses
- **Inflow Sources**:
    - Bhima River
    - Rainfall from catchment stations: Dhund, Sarati

## 2. Model Equations

**Decision Variables:**

X1 = Wheat produced in quintal
X2 = Maize produced in quintal
X3 = Groundnut produced in quintal
X4 = Sugarcane produced in quintal
X5 = Bajra produced in quintal
X6 = Cotton produced in quintal
X7 = Jowar produced in quintal

**Objective Function:** Maximize total profit from crops produced:

**Maximize Z = ΣPiXi**

**Constraints:**

1. **Total area constraint:** ΣAi * Xi * w1(t,i) <= total_area
2. **Storage balance equation:** S(t+1) = S(t) + R(t) -ΣWiXi - K - I - St
3. **Crops production should be positive**: Xi >=0
4. **Minimum storage**: S(t) >= S0
5. **Storage capacity:** S(t) <= S1
6. **Spill should be positive:** St >= 0
7. **Environmental constraint:** Σepsilon_i * xi <= epsilon_max

**Timescale:**

- Monthly timestep
- Duration: June 2023 – May 2024

**Software Used:** Lingo

**Note:** Our model considers mainly the areas of Pune and Solapur. Also we have taken the rainfall data from two stations Sarati and Dhond and we have used the weighted average method to calculate the rainfall that goes to the Ujjani reservoir.

## 3. Data Sources

- **Ai** - represent the area required in meter square for the production of 1 quintal of the ith crop.
- **W1(t,j)** - represents if the land is used for the jth crop in month t.
- **S(t)** - represent the storage of the dam in month t in meter cube
- **R(t)** - represent the rainfall in the month t in meter cube
- **W(t,j)** - represent the water required in meter cube to grow 1 quintal of the jth crop in t month
- **K** - represent the domestic use of water in that month in meter cube
- **L** - represent the industrial use of water in that month in meter cube
- **S0** - minimum capacity storage for the dam
- **S1** - maximum capacity of the dam
- **Epsilon_i** - represent the pesticide generated in g to generate 1 quintal crop.
- **Pi** - Profit from each crop

| 1 | Column 1 | Wheat | maize | Groundnu | Sugarcane | bajra | Cotton(m | jowar |
|---|---|---|---|---|---|---|---|---|
| 2 | January | 24.81 | 0 | 0 | 7.775 | 0 | 0 | 0 |
| 3 | February | 24.81 | 0 | 0 | 6.384 | 0 | 0 | 0 |
| 4 | March | 24.81 | 0 | 0 | 12.669 | 0 | 0 | 0 |
| 5 | April | 0 | 0 | 0 | 18.021 | 0 | 0 | 0 |
| 6 | May | 0 | 0 | 0 | 29.242 | 0 | 0 | 0 |
| 7 | June | 0 | 25.66 | 12.4 | 37.479 | 22.34 | 44.28 | 40.69 |
| 8 | July | 0 | 25.66 | 27.97 | 51.256 | 22.34 | 85.7 | 74.92 |
| 9 | August | 0 | 25.66 | 45.37 | 46.298 | 22.34 | 125.57 | 113.09 |
| 10 | September | 0 | 25.66 | 68.9 | 36.097 | 22.34 | 47.97 | 48.4 |
| 11 | October | 0 | 25.66 | 33.35 | 30.591 | 22.34 | 49.59 | 0 |
| 12 | November | 24.81 | 0 | 0 | 27.63 | 0 | 0 | 0 |
| 13 | December | 24.81 | 0 | 0 | 21.224 | 0 | 0 | 0 |
| 14 | pesticide (g/hec) | 500 | 1450 | 1000 | 1000 | 1000 | 1000 | 1000 |
| 15 | pesticide (g/quintal) | 13.69 | 28.62 | 41.72 | 4.43 | 41.3 | 79.36 | 54.68 |
| 16 | pesticide(rs/quintal) | 46.54 | 97.3 | 141.8 | 15.062 | 140.4 | 269.8 | 185.912 |
| 17 | area (m2/quintal) | 275.3 | 197.4 | 417.2 | 44.3 | 412.9 | 793.5 | 546.8 |
| 18 | profit(rs/quintal) | 1174.15 | 1223.02 | 4872.47 | 305 | 1472.55 | 6139.41 | 2115.27 |

***Table 1: Water requirement along with profit for the crops***

| Crop | Cost of Production (Rs./quintal) | Yield (quintal/acre) | Gross Returns (Rs./acre) |
|---|---|---|---|
| Rice | 2408 | 19.8 | 47678 |
| Wheat | 1174 | 14.7 | 17260 |
| Maize | 1223 | 20.5 | 25072 |
| Bajra | 1481 | 9.8 | 14431 |
| Jowar | 2118 | 7.4 | 15653 |
| Ragi | 2571 | 9.6 | 23481 |
| Gram | 3798 | 6.8 | 25832 |
| Tur (Arhar | 5133 | 4.9 | 25152 |
| Groundnu | 4892 | 9.7 | 47263 |
| Cotton | 6462 | 5.1 | 31311 |
| sugarcane | 157 | 91.3 | 27846 |

***Table 2: Yield of the crops***

| Month | Rainfall(mm) | Reservoir(m3) | Agricultural(m | Total(m3) |
|---|---|---|---|---|
| June | 18.60355677 | 276411646.5 | 33970094665 | 34246506311 |
| July | 181.0139535 | 2689505321 | 3.30531E+11 | 3.33221E+11 |
| August | 32.52093023 | 483195981.4 | 59383218605 | 59866414586 |
| Septembe | 257.4214318 | 3824767634 | 4.70052E+11 | 4.73876E+11 |
| October | 61.05180119 | 907107662 | 1.11481E+11 | 1.12388E+11 |
| November | 46.16087551 | 685858288.4 | 84289758687 | 84975616975 |
| December | 43.00911993 | 639029503.9 | 78534652987 | 79173682491 |
| January | 11.73005016 | 174285085.3 | 21419071591 | 21593356677 |
| February | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 |
| April | 0.016598267 | 246617.0543 | 30308435.93 | 30555052.99 |
| May | 174.9934337 | 2600052437 | 3.19538E+11 | 3.22138E+11 |

***Table 3: Monthly Rainfall Data***

The following variables were used as data in the optimization problem:

- **Rainfall Data:** India-WRIS extracted dataset
- **Reservoir storage:** Monthly WRIS Excel file
- **Irrigation demand:** Estimated using IWMI + WRD Maharashtra reports

- Crop season: https://www.mpcb.gov.in/sites/default/files/public_hearing/exe_summary/2020-04/Exe_SumSangolaLIS.pdf
- Yield data: https://www.agrifarming.in/cost-of-farming-per-acre-in-india-calculator-for-state-wise-cultivation-input-cost-per-acre#google_vignette https://www.vsisugar.com/vsi_admin/images/sugar_statistics/4.Indian%20statewise%20Yld%20%28202223%29.pdf
- Crop Water requirement:
    - Wheat:https://www.agricultureinindia.net/agronomy/wheat-production/water-requirement-for-wheat-production-agronomy/12017
    - Maize: https://echoupaladvisory.in/pop/maize-water-management-en/
    - Bajra: https://eagronomy.com/pearl-millet/
    - Groundnut: https://www.jains.com/PDF/Crop%20Knowledge/Groundnut.pdf
    - Sugarcane:https://iwaponline.com/wpt/article/18/3/685/93652/Estimation-of-irrigation-water-requirement-and
    - Cotton:https://www.ijcmas.com/13-3-2024/Sachin%20%20Phad,%20et%20al.pdf
    - Jowar:https://www.agricultureinindia.net/agronomy/sorghum-cultivation/sorghum-cultivation-how-to-cultivate-sorghum-in-india/19686
    -
- Environment constraint : https://www.efsa.europa.eu/en
- Total Area for cultivation: https://www.researchgate.net/figure/ndex-map-of-Ujjani-dam-Maharashtra-state-India_fig1_342302756
- Catchment area: https://www.irjet.net/archives/V4/i8/IRJET-V4I8223.pdf
- Domestic water use : https://pure.iiasa.ac.at/id/eprint/19014/1/WFB%20Nexus%20Situational%20Analysis%20Bhima%20Basin%20Kanade%20et%20al%202023.pdf https://www.hindustantimes.com/cities/mumbai-news/15-years-on-water-continues-to-fuel-madha-s-politics-101714504296946.html
- Maximum capacity of dam : https://en.wikipedia.org/wiki/Ujjani_Dam
- Industrial water use : https://www.hindustantimes.com/cities/pune-news/pmc-sets-water-budget-for-2024-25-at-21-48-tmc-101722971053457.html

https://www.slideshare.net/slideshow/water-supply-of-solapurdrinking-water-supply-schemes-for-solapur-town-development-problems-future-a-review-for-last-125-years-by-dr-vadagbalkar-sk-head-geology-department-dayanand-institutions-solapur-413002-maharashtra-state-india/5259838

## 4. Results and Discussion

The optimal strategy heavily favors Wheat and Groundnut, allocating resources to produce substantial quantities of these crops. Cotton is also selected, but at a negligible level (1104 quintals) compared to Wheat and Groundnut. The remaining crops (Maize, Sugarcane, Bajra, Jowar) were not found to be profitable to produce under the current resource constraints and economic parameters. This indicates that Wheat and Groundnut offer the most favorable combination of profitability (p(j)) relative to their consumption of the binding resources (land, water in specific periods, fertilizer).

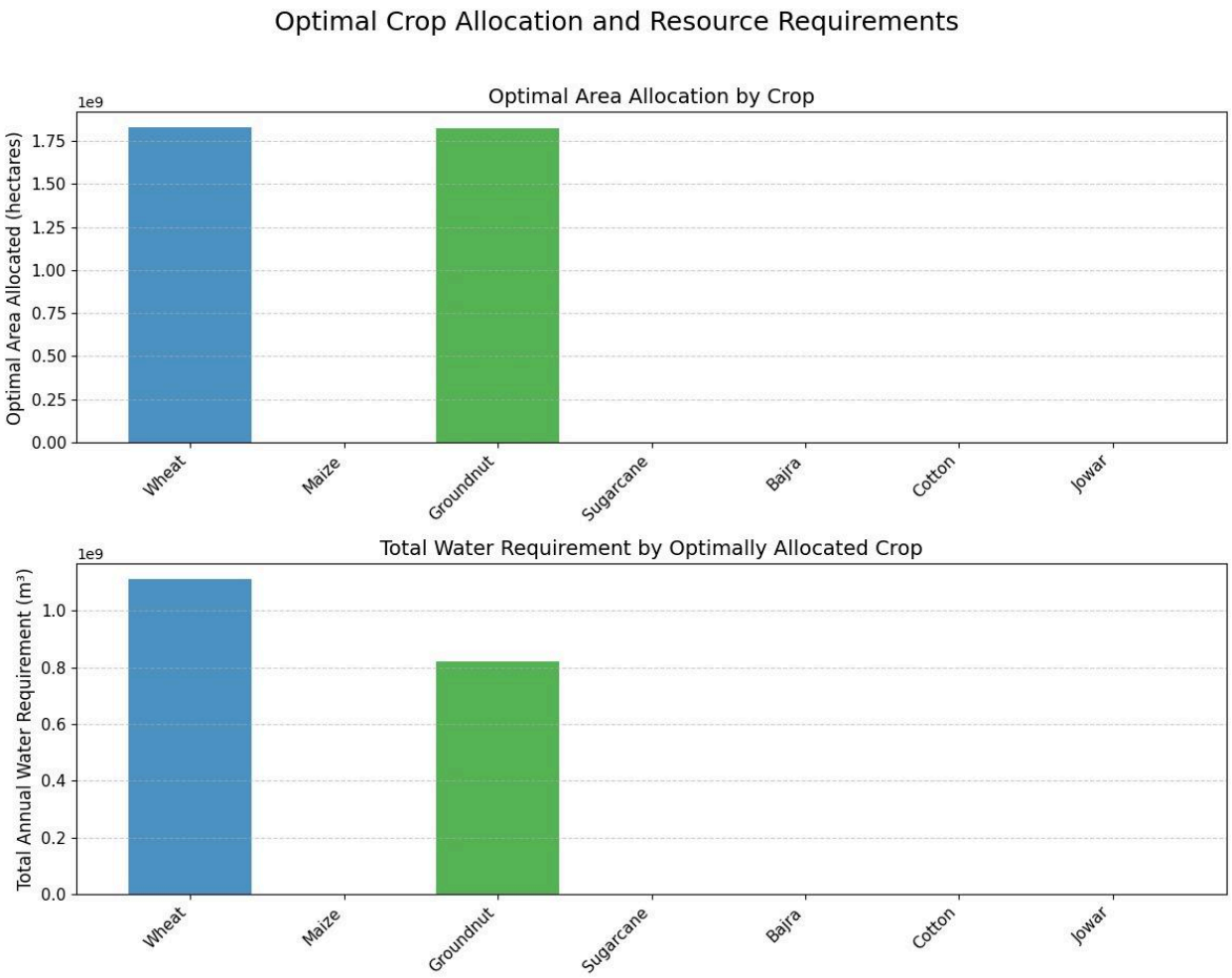



***Figure1: (a) Optimal Area allocation vs Crop & (b) Total water requirement vs crop***

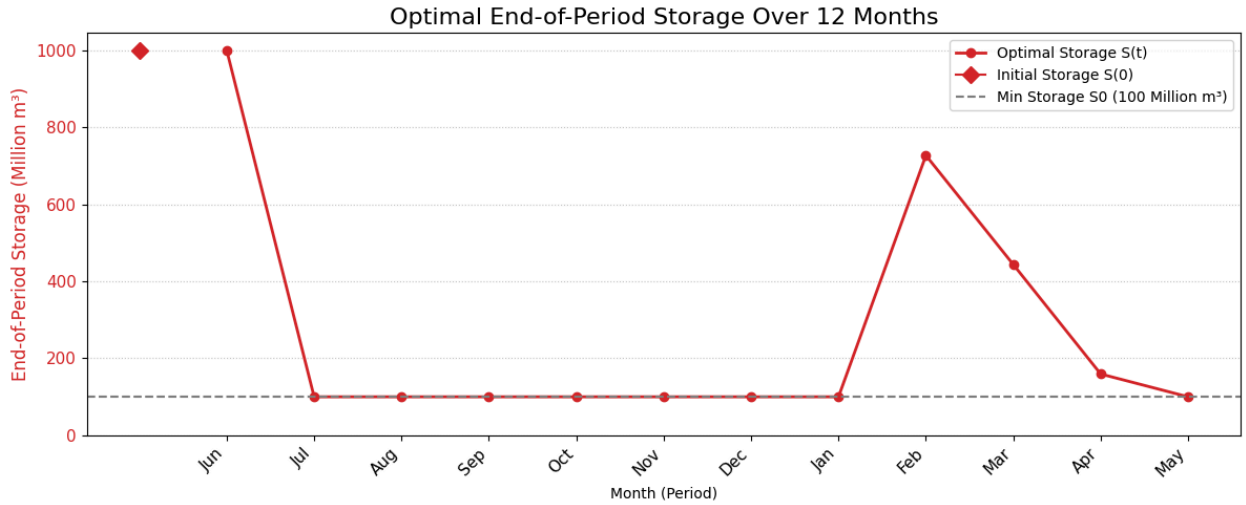



***Figure2: Optimal End of period storage vs Monthly inflow***

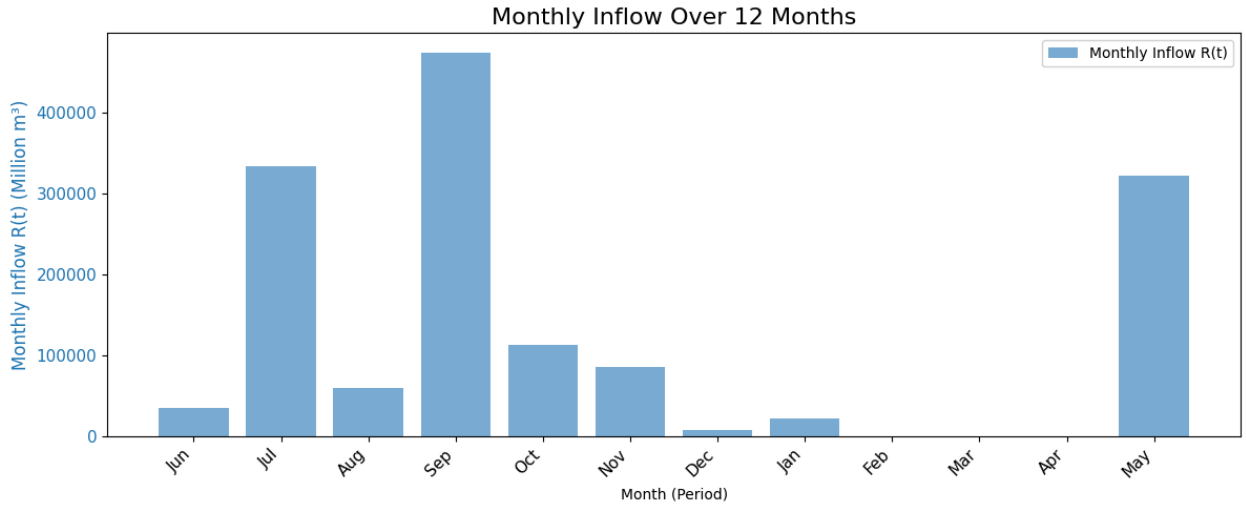



***Figure3: Optimal End of period storage vs Monthly inflow***

| | |
|---|---|
| X( 1) | 8950980. |
| X( 2) | 0.000000 |
| X( 3) | 4376798. |
| X( 4) | 0.000000 |
| X( 5) | 0.000000 |
| X( 6) | 1103.858 |
| X( 7) | 0.000000 |

***Table 4: optimal production of crop in quintals***

## 5. Conclusion

- **Optimization Goal:** Maximized annual net agricultural benefit (approx. Rs. 3184 Cr) using Linear Programming under resource constraints.
- **Optimal Crops:** The model predominantly selected Wheat (8.95 M quintals) and Groundnut (4.38 M quintals), with negligible Cotton, as the most profitable choices given resource limits.
- **Binding Constraints:** The optimal solution was simultaneously limited by Land, Fertilizer, and Water Availability (in multiple critical months).
- **Water Stress:** Reservoir storage operated at the minimum allowable level (100 $Mm^3$) for 9 out of 12 months, indicating high water stress and potential unreliability under the modeled demands.