Comparative wastewater quality indicators and Multivariate analysis of Riyadh sewage treatment plants and its impact on irrigation of Riyadh District

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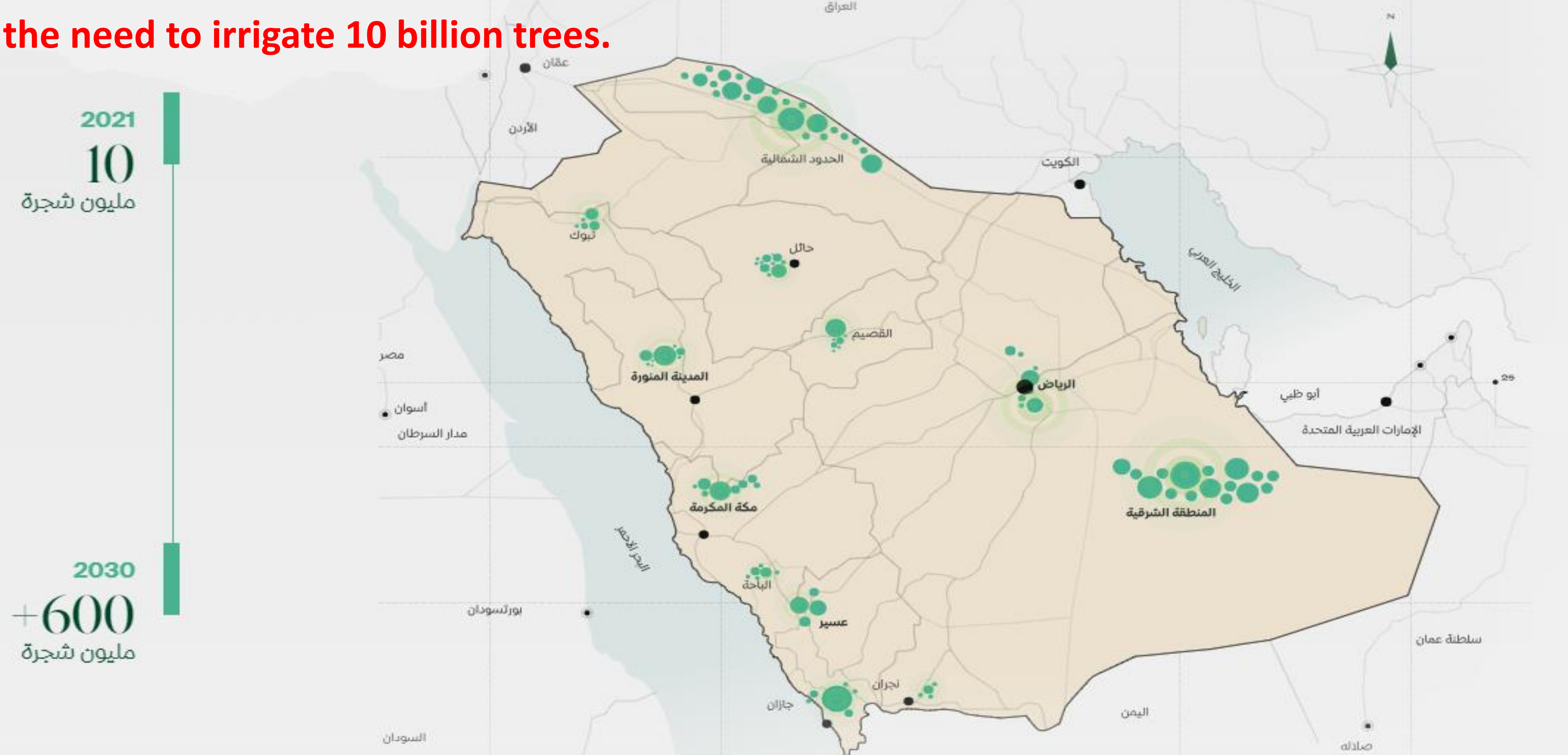
رحلة المملكة لزراعة ١٠ مليارات شجرة

Saudi Arabia faces a shortage of annual water due to its extensive afforestation initiatives and the need to irrigate 10 billion trees.



Introduction

- The Treated wastewater (TWW) use in agriculture equals **400 million** m^3, which represents 37.6% of TWW in Saudi Arabia.
- The amount of TWW in Riyadh is 556 million m^3 in 2021, however, only 41.9 million m3, or 7.5%, of that is **used for agriculture** (MEWA, 2021).
- According to the 2030 Saudi Vision, Saudi Arabia intends by 2025 to entirely use TWW to reach 100% utilization of TWW.
- The total annual capacity of the 133 WWTPs in Saudi Arabia is 1.87 billion m3. In the future, TWW will be depended on as unconventional water resources, especially after the green Riyadh project (RCRC, 2021).

The importance of the study

- TWW is available all year and contains nutrients required for agricultural growth (Mancuso et al., 2022). So, it can be used as a source throughout the year.
- TWW might be a component of the solutions to supply the water needed for this green Riyadh project .So, it is necessary to confirm the source's quality before using it for irrigation.
- The study assessed **water quality, pollution, and suitability for irrigation** by analyzing historical TWW data from wastewater treatment plants in the province of Riyadh over a four-year period.

Objectives

The purpose of the study is

1. to examine the temporal variations in the features of TWW quality as well as the key factors affecting TWW quality.
2. to ascertain if TWW is suitable for irrigation,
3. to comprehend the statistical relationship between parameters.
4. to explain how the factors related to wastewater quality affect the CWQI and show how to reduce the redundant variables by using PCA in conjunction with statistical techniques.

Methodology

- Riyadh is the capital of Saudi Arabia. It has population of 7.5 million (25 % of total population) (GASTAT, 2018).

- **Description of Riyadh wastewater Treatments plants**

- Riyadh is divided into four populated areas: East Riyadh, North Riyadh, Manfouha, and Heet as described in details shown in Table 1.

Wastewater Plant	Design capacity (m^3/day)	Technology	Treatment Type	Purpose
Manfouha	North 200000 South 200000 East 200000	Trickling filter activated sludge	Tertiary	Agriculture irrigation
Heet-Alkharj	Phase I 100000 Phase II 100000 Phase III 200000	activated sludge	Tertiary	Groundwater recharge
Alhayer	Phase I 400000	activated sludge	Tertiary	Irrigation and groundwater recharge
Refinery	20000	Clarification& filtration	Tertiary	Agriculture irrigation

TWW quality parameters

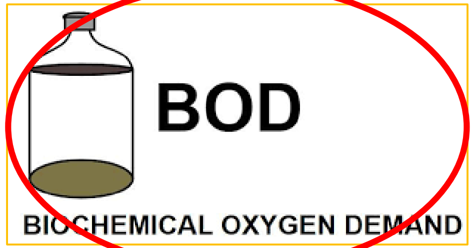
- The historical TWW parameters data were collected for four years from WWTPs, which are located in the Riyadh province (Table 1).
- The TWW quality parameters included thirteen parameters: chemical oxygen demand (COD) (mg L^{-1}), dissolved oxygen (DO) (mg L^{-1}), Cl^- (mg L^{-1}), Na^+ (meq L^{-1}), Ca^{++} (meq L^{-1}), Mg^{++} (meq L^{-1}), NH_4^+-N (mg L^{-1}), NO_3^--N (mg L^{-1}), total dissolved solids (TDS) (mg L^{-1}), EC (dS.m^{-1}), pH, turbidity and Escherichia coli (E.coli) (Cell/100ml).
- All sampling and analytical techniques were carried out following the American Public Health Association (Greenberg et al.,1992)

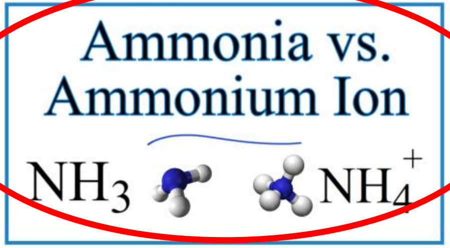
TWW quality parameters data

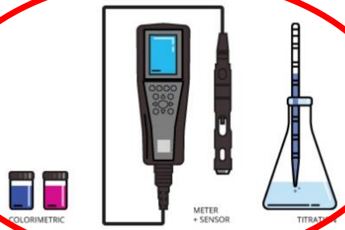
- Chemical oxygen demand (COD),
- The microbiological analysis
- The ammonia (NH4) , Nitrogen (N)
- Turbidity
- The EC

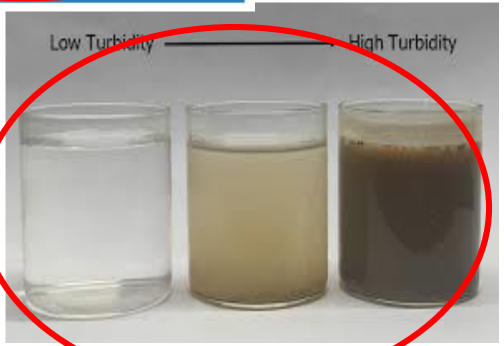
  The pH

➢ dissolved oxygen (Do)









Water quality indices

- The are twenty-one different WQI models
- Such as
- ➢ Horton WQI 1960
- ➢ Oregon Index (1980):
- ➢ British Colombia Index(1995)
- ➢ Canadian Council of Ministers of the Environment (CCME) (2001)

Summary of WQI model applications (in total and by study area) found in literature published from 1960 to 2019.

WQImodel	Number of Applications	Type of Study Area		
		River	Lake	Marine/coastal/sea
CCME	36	28	5	3
NSF	18	17	1	–
FIS	12	10	1	1
MWQI	8	6	1	1
Horton	7	6	–	1
SRDD	6	6	–	–
Bascaron	4	3	–	1
EQI	2	1	1	–
Oregon	2	2	–	–
Smith	2	2	–	–
Almedia	1	1	–	–
BCWQI	1	1	–	–
Dalmatian	1	–	–	1
Dojildo	1	1	–	–
Dinius	1	1	–	–
Hanh index	1	1	–	–
House index	1	1	–	–
Liou index	1	1	–	–
Said	1	–	–	1
WJWQI	1	–	–	1

The equations for Canadian Wastewater Quality Index (CWQI)

- $$F1=\frac{\text{number of failed parameters}}{\text{total number of parameters}} \quad (1)$$
- $$F2=\frac{\text{number of failed tests}}{\text{total number of tests}} \quad (2)$$
- $$\text{Extrusion}=\frac{\text{failed test value}}{\text{limitation}}-1 \quad (3)$$
- $$\text{nes}=\frac{\sum_{i=1}^{n}\text{extrusioni}}{\text{number f tests}} \quad (4)$$
- $$F3=\frac{\text{nes}}{0.01\text{nes}+0.01} \quad (5)$$
- $$\text{CWWQI}=100-\frac{\sqrt{F1+F2+F3}}{1.732} \quad (6)$$

CCWQI ranking

Quality range	CWWQI	Water category
Excellent	95-100	Very close to natural or pristine levels
Good	80-94	Rarely depart from natural or desirable levels
Fair	65-79	Sometimes depart from natural or desirable levels
Marginal	45-64	often depart from natural or desirable levels
Poor	0- 44	Quality is almost always threatened or impaired

Comprehensive pollution index (CPI)

- $Pi = \frac{\text{Measured concentration of individual parameter}}{\text{Standard permissible concentration of parameter}}$ (7)
- $CPI = \frac{1}{n}\sum_{n}^{1} Pi$ (8)
- where Pi is the index of single parameter of water quality measured, n is number of the parameters.
- CPI ranges defined between 0 to 2.

The multivariate analysis

- The multivariate statistical analysis such as principal component analysis (PCA) will be utilized for understanding **the key factors of water quality parameters**.
- PCA can **decrease of the number of input variables** in order to create simple and reliable prediction models to correlate target variables.
- The statistical analysis was conducted out using the XLSTAT application (Version 2018; Excel Add-ins soft SARL, New York, NY, USA)

Results

The classification of TWW parameters samples from Riyadh TWWPs, over four years, based on the standard limit for restricted irrigation.

Parameters	Restricted irrigation Standards	Over the limit (%)	Below the limit (%)	Comprehensive Pollution index (CPI) (Mean +STDEV)	CPI (Max)	CPI (Min)
Free chlorine (mg/L)	0.5	8.33	91.67	0.44±0.09	2.08	0.06
Dissolved oxygen (DO) (mg/L)	-	0.00	0.00	-		
SAR	11.3	0.00	100.00	0.42±0.08	0.72	0.24
Na (mg/L)	40	0.00	100.00	0.48±0.11	0.98	0.22
Ca+ Mg (mg/l)	50	0.00	100.00	-	0.42	0.26
E. coli (100 cell/mm)	1000	4.17	95.83	0.45±0.12	0.75	0.00
COD (mg/L)	80	18.75	81.25	0.93±0.77	4.1	0.27
NO_3 (mg/L)	10	29.17	70.83	0.89±0.52	2.67	0.01
NH_4 (mg/L)	5	39.58	60.42	1.39±0.75	4.02	0.01
Turbidity (NTU)	5.8	56.25	43.75	0.51±0.03	0.57	0.44
TDS (mg/L)	2500	0.00	100.00	0.73±0.39	3.33	0.45
EC (mg/L)	3	0.00	100.00	0.73±.0.93	3.33	0.58
pH	6-8.4	0.00	100.00	0.87±0.02	0.9	0.79

- **The water quality of TWW in Riyadh TWWPs were slightly polluted, however, there is no significant public health risks linked to the reuse of these treated wastewater, particularly for irrigated crops throughout the entire period.**
- The CPI results were found to vary in the range 0.06-2.8 for free chlorine (slightly polluted), whereas for SAR the CPI results varied from 0.24-.27 (slightly polluted), however in the Na from 0.26 - 0.98 (slightly polluted).
- The CPI results were found to vary in the range 0.27- 0.75 (slightly polluted) for E. coli, whereas for COD varied in the range 0.01- 4.01 with average 0.93 (slightly polluted).
- The CPI results of NO_3-N varied from 0.01- 2.67 (slightly polluted).
- The CPI results of NH_4-N varied from 0.44- 4.02 (slightly polluted).
- The CPI results of TDS and EC varied from 0.58- 3.33, and 0.79 – 0.9, respectively.
- **The study found that 43.75% of turbidity data exceeded the maximum permitted level for RI. This might be because of inadequate influent treatment or elevated turbidity, which lowers chlorine effectiveness in water with high COD and turbidity**

Canadian wastewater quality index (CWQI)

Months	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
CWQI	74.23	81.64	88.93	81.60	84.58	84.86	82.43	88.94	88.31	79.86	86.86	90.89
Classification	fair	good	good	good	good	good	good	good	good	fair	good	good
Months	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14
CWQI	82.28	85.36	82.34	90.07	85.26	85.38	82.07	90.10	84.68	79.75	85.53	85.26
Classification	good	good	good	good	good	good	good	excellent	good	fair	good	good
Months	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15
CWQI	84.75	78.85	80.28	81.32	79.65	77.01	79.91	83.88	87.11	85.93	90.44	73.57
Classification	good	fair	good	good	good	fair	fair	good	good	good	good	fair
Months	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
CWQI	79.96	80.89	83.14	83.35	94.19	78.10	90.88	89.87	90.35	95.26	83.98	83.71
Classification	fair	good	good	good	excellent	fair	good	good	good	excellent	good	good

The principle component analysis

Eigen value of the six components.

	F1	F2	F3	F4	F5
Eigenvalue	2.004	1.402	1.248	1.133	1.074
Variability (%)	18.215	12.741	11.348	10.302	9.761
Cumulative %	18.215	30.956	42.304	52.606	62.367

- The first primary component (PC1) in the dataset, which accounts for 18.2% of the total information, was the most important component.
- This component can provide a dominant pattern of the dataset to aid in understanding the TWW's qualities. It reflected the parameters loading of Ca+Mg, EC, NO^3 and turbidity.
- The second component, which accounts for 12.7% of the data variation, was including NH^4, COD, and DO.

Regression analysis

Model	R	R^2	MSE	Adjusted R^2	Sum of square	df	Meanof square	F	P -value
1	0.842	0.708	7.786	0.657	756.146	7	108.021	13.874	< 0.0001
2	0.789	0.623	9.354	0.588	665.356	4	166.339	17.783	< 0.0001
3	0.756	0.571	10.652	0.531	609.553	4	152.388	14.306	< 0.0001
4	0.721	0.519	11.665	0.486	554.313	3	184.771	15.840	< 0.0001
5	0.690	0.477	12.414	0.453	508.931	2	254.466	20.498	< 0.0001

Predicators

[1]free chlorine / Na / E. COLI / NO3 / NH4 / turbidity / pH

[2]NO_3 / NH_4 / turbidity / pH

[3]Ca Mg / NO_3 / NH4 / turbidity

[4]Ca Mg / NO_3 / turbidity

[5]NO_3 / turbidity

The CWQI equations for the selected TWW quality parameters

Model 1	[1]CWQI = 173.93-3.99*free chlorine-0.46*Na-2.47-03*E. COLI-0.26*NO_3-0.59*NH_4-0.37*turbidity-10.232*pH
Model 2	[2]CWQI=150.18-0.23*NO_3-0.61*NH_4-0.47*turbidity-7.81*pH
Model 3	[3]CWQI=97.14-0.37*CaMg-0.25*NO_3-0.423*NH_4-0.53*turbidity
Model 4	[4]CWQI=95.04-0.36*CaMg-0.23*NO_3-0.54*turbidity
Model 5	[5]CWQI=91.1-0.24*NO_3-0.57*turbidity

Conclusion

- TDC, pH, free chlorine, SAR, Na, Do and Ca+Mg parameters did not exceed the maximum levels allowed for restricted irrigation.
- The average CPI values ranged from 0.16 to 1.61, indicating modest pollution throughout the study.
- The CWQI outcomes were ranged between 73.75 to 95.26%, indicating that reuse of treated wastewater could not harm public health, especially for irrigated crops.

Cont.

- The principal component analysis of a wastewater dataset reveals that the first major component, accounting for 18.2% of the total, is the most important, displaying parameter loading for TWW features of EC, Ca+Mg, turbidity, NO_3. The second component exists NH_4, COD, and DO.
- The study found a strong correlation between turbidity, nitrite, and CWQI.
- A stepwise regression model was used to predict CWQI, with Model 5 having the fewest variables. Model 1 was the best.
- The results may also benefit farming methods that preserve soil health and water sustainability.

Practical implications of the findings

- The outcomes of this study have the potential to improve the environment and welfare of the community by establishing evidence-based regulations for wastewater management and agriculture in Riyadh.
- The findings can guide the development of evidence-based policies and recommendations for Riyadh's agricultural and wastewater management, aiding in monitoring plans, and setting water quality goals.
- Understanding current trends and potential future changes can also aid in long-term planning initiatives like infrastructure development and land-use planning.
- Policymakers may utilize the study's conclusions to direct funding toward the implementation of pollution control legislation and program monitoring and support sustainable production

Credits and Acknowledgements (if any)

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Final Remarks to Presenters and Submission

The challenges we will face problems such as

- What is the restrictions for TWW reuse?
- What are the suitable areas for TWW reuse?
- The optimal allocating these resources to several crops to get the maximum benefit?

Future of Research