Journal of Economic Sciences
Volume 4, Issue 1
https://www.jesciences.com

Assessing Water Use Efficiency of Cotton Crop in Pakistan: Impact of Geo-climatic and Socio-economic Factors

Nusrat Yaqoob [1,*], ***Zakir Hussain Dahri*** [2]

Affiliations
1. Department of Economics, University of Karachi
2. Sindh Agriculture Research Council (SARC-PARC)

*Corresponding Author Email: nusratbaloch0301@gmail.com

Timeline
Received: Dec 05, 2024
Revised: Dec 28, 2024
Accepted: Dec 29, 2024
Published: Jan 15, 2024

DOI
https://doi.org/10.55603/jes.v4i1.a2

Abstract
The problem of water stress and scarcity is likely to be worsening in the coming years ahead in Pakistan. Cotton crop is a major raw material for the manufacturing sector in Pakistan and the textile industry accounts overall 75 % of the manufacturing sector of the country. This study has tested the hypothesis, of whether a significant relationship exists between water use efficiency of cotton crop (WUEc) and geo-climatic and socio-economic factors or not. To check the water use efficiency of the cotton crop for each province separately, the formula of farm field water use efficiency is used to obtain the WUEc (Sindh and Punjab). Following that to check the stationarity of univariate series Philips -Perron unit root test is applied. Subsequently, the Auto Regressive Distribution Lag (ARDL) Model is used to find the cointegration in the long run. The results of the study have disclosed that environmental factors have a significant relationship with the water use efficiency of the crop, and the misallocation of government resources at the national and provincial levels is the main reason for water usage inefficiencies in Pakistan. Therefore, at the policy-making level sustainable economic growth objectives need to be prioritized and planned investment must be directed towards the conservation of natural water resource management and improvement of human capital to disseminate smart water agriculture practices among medium and small farmers.

Keywords: *Water Use Efficiency, Cotton, Manufacturing, Geo-climatic, Socio-economic*

JEL Classification: *Q1, Q2, Q3, Q4, Q5. Q56, Q53*

1. Introduction
Water is a fundamental for human, consequently crop water use efficiency is a multifaceted concept. Particularly, water security dilemma is largest in the arid climatic region, where potential evaporation is larger than precipitation and the situation constitutes a formidable challenge. Since, it not only affects crop productivity but also serves as an indicator of the impact of socio-economic factors on water governance, management and distribution (Barros, 2013). For this reason, natural resource economists very recently started to find out the correlation between crop water use efficiency and its relationship with other important socio-economic and climatic factors and Pakistan has no exception, because the country is located in the northern hemisphere (Khan, et al., 2024).

Extreme weather events are complex in nature and there are numerous interrelated factors that affects a country's sensitive geographical characteristics. The long-term climate index indicates that Pakistan ranks 8th in the list of most affected from 2000 to 2019. The agriculture sector is the most affected sector due to the climatic variation, particularly the cotton zones in the country are situated in arid and semi- arid geographical settings. Therefore, scarcity of natural resources and the mounting population pressure in cotton zones in Pakistan is a key driver to increase in cropping intensity. Resultantly, the frequent stress on natural resources such as on water and land has already been documented. This is the reason why Pakistan lies on to the ascending limb of environmental Kuznets curve. (Nazir, et al., 2024; Naz and Kousar, 2024; Ajani and van der Geest, 2021; Hatfield and Dold, 2019;). Because water resources are the most important component for agriculture productivity, particularly during extreme weather conditions. So, it is imperative to assess how much water is actually required, because climate change is already contributing into the overall water use efficiency for other sectors as well. Even though, for a century, scientific advancement has fueled agricultural progress globally. However, Pakistan still faces significant challenges in achieving sustainable development goals 1,2, and 6 due to climatic stress, including increased in droughts, floods, unpredictable rainfall, and population growth (Mujtaba et al., 2024; Fatima, and Imran, 2024; Sarwar et al., 2024; Fazeli et al., 2018).

Punjab and Sindh are the two main provinces where cotton crop is being cultivated, but the crop cultivation in Pakistan is vulnerable due to the above said challenges. Despite the fact that the country was once ranked 5th globally by 2019, however, over the years cotton production has declined significantly in the country along with the decreased in yield kg per acer since 2009, (Ashraf, et al.,2018). This declined is attributed to factors such as climate change, reduced cultivation area, water scarcity and pest infestation. Consequently, the country is facing a growing reliance on cotton imports which is impacting the economy by increasing the raw material cost for textile industry (Chaudhary et al., 2024; Sengupta and Thangavel, 2023; Janjua and Hassan, 2020; Ali et al., 2019; Hoekstra et al., 2011; Hoekstra and Hung, 2005). Because cotton is a water intensive crop requiring significant amount of water for one plant than to other major crops like maize and pulses (Iqbal et al., 2024; Saeed. et al., 2024; Iqbal, et al., 2023; FAO 2021). Moreover, over abstraction of groundwater in a cotton producing areas of the provinces (Punjab and Sindh) is increasing substantially, which is a leading cause to declining soil moisture. This becomes critical during dry years due to reduced rainfall, and increase in water demand. Resulting in decreased overall agricultural production and lower revenue generation for the year.

Therefore, the main objective of the study is to explore cotton water use efficiency in Sindh and Punjab by integrating both geo-climatic and socioeconomic factors. Additionally, the study addresses the common observation of increasing crop yield per acre while maintaining long-term water resource sustainability. Therefore, the research study takes the three-research questions: first, is the cotton yield per acre in Pakistan correlating with higher water intake? second, which province excels in managing surface water resources for cotton crop yield? and third, are socio-economic factors pertinent to crop water use efficiency? All the above-mentioned study questions are critical to achieving a long-term prospectus of Pakistan's agricultural growth. Especially for the integration of smart water management practices in the cultivated area. As over the years decreased in groundwater level and declining soil moisture have significantly increased water demand for cotton cultivation (Shahzad et al., 2022; Javed et al., 2015; Zulfiqar and Thapa, 2021; Muhammad et al., 2022; Nasir et al., 2021; Razzaq et al., 2019). Indeed, a critical knowledge gap exists regarding the impact of inefficient farm water use management practices amidst climate change and the specific microenvironmental factors that are limiting cotton production. This study aims to address this gap by examining the factors influencing cotton water use efficiency (WUE) in Pakistan.

In epitome, for agricultural growth, the cotton water use efficiency analysis is an important subject matter, due to being water intensive and major cash crop of Pakistan. Therefore, the study is a comprehensive assessment of cotton water use efficiency as it concurrently examines both of the factors: the effects of population pressure on water availability at the farm gate; role of farm inputs in farm yield over the years by taken into account climatic variation. A comprehensive approach of this nature has not been extensively undertaken in the past. (Tokel, et al. 2022; Wani et al., 2022; Zulfiqar et al., 2021; Jamil et al., 2021; Jeswani, and Azapagic, 2011; Sunding, 2005, Kijne, et al., 2003). The study subsequent sections are as follows: literature review, conceptual framework and hypothesis development, research methodology, results and conclusion with the sub heading of policy implications.

2. Literature Review

Water security is a critical concern, particularly in arid regions where potential evapotranspiration exceeds precipitation. This scarcity poses a significant challenge, especially considering the growing demand for water and other natural resources driven by a burgeoning population particularly in the less developed countries. This urgency underscores the need for research to support the integration of sustainable agricultural farming practices. (Falkenmark and Rockström, 2006). The concept of water use efficiency was first introduced by Briggs and Shantz (1913), who investigated the relationship between plant productivity and water consumption. Since then, numerous studies have explored various aspects of water use efficiency in agriculture. Dong et al., (2014) evaluated China's interprovincial water disparities using an inter-regional input-output model. Their findings revealed a strong correlation between provincial water foot prints and GDP, highlighting that northern and western province often water -scarce are net water importers. Tiwari et al., (2015), investigated the relationship between crop productivity and climate variation in Nepal. They analyzed data on four major cash crops (paddy, maize, wheat, and potato) from 1975 to 2011), considering factors such as temperature, rainfall and economic variables. Their multivariate regression analysis demonstrated a significant impact of climate variables on crop yield, with heterogenous effects observed across different crop and locations. These findings emphasize the crucial role of climate in determining crop productivity, particularly withing the growing season. Xue et al. (2017) examined the impact of water consumption efficiency and productivity on sustainable food supply in China. They analyzed data from two major irrigation districts, focusing on the role of regional evapotranspiration from groundwater (ETg) and regional evapotranspiration (ET). Their findings indicated that water saving practices are more effective in arid and semi-arid regions, where shallow groundwater contributes significantly to irrigation. This research highlights the importance of shallow groundwater in enhancing regional water consumption efficiency and productivity, ultimately contributing to increased agricultural output.

Wang et al., (2020), observed rapid economic growth in China's agricultural sector between 2000 and 2017, with a significant increase in GDP share. This growth, however, was accompanied by a substantial rise in agriculture water consumption. Utilizing panel data from 31 Chinese provinces and employing stochastic frontier analysis, the study found that agriculture water use efficiency (AWUE) has improved over time. It is primarily by government investment in infrastructure development and education. Key influencing AWUE factors are: per capita income, primary school enrollment ratio, total sown area, reservoir storage capacity, and the use of water saving technologies such as electric and diesel motors. The research also highlights the significant role of socio-economic factors in enhancing water use efficiency within Chinese agricultural context. Similarly in Pakistan, Abbas, S. (2020) investigates the impact of climate change, area under cultivation, and fertilizer consumption on cotton production in Pakistan from 1980 to 2018. Employing an Autoregressive Distributed Lag (ARDL) model, we find cointegration among the variables. Though increase in temperatures have an insignificant positive impact on cotton yield, suggesting that higher temperatures do not necessarily lead to increased production. A significant positive effect is observed in both the long run and short run. The study emphasizes the need for Pakistan to mitigate climate change through measures such as forestation, dam construction, and the adoption of environmentally friendly agricultural practices to enhance cotton production and ensure sustainable agricultural development.

Zulfiqar, and Thapa, (2021), examined water security challenges in cotton production in Punjab, Pakistan. Findings revealed that inefficient irrigation practices, particularly excessive flood irrigation, significantly contributes to water losses and declining groundwater levels. Despite economics importance of cotton crop the water use inefficiency negatively impacts the environment. The results of the study found that improving water use efficiency in cotton production is possible, with potential for at least a 14% increase. Policy recommendations emphasize the adoption of more efficient irrigation methods, such as drip or sprinkler irrigation, to enhance water use efficiency and mitigate environmental impacts in cotton production across Pakistan and other South Asian countries.

Zhou et al. (2022) investigated the impact of urbanization on AWUE on 30 Chines province from 1999 to 2018. Using the super SBM model to measure AWUE and an entropy -based index to evaluate urbanization, their analysis, conducted through a dynamic spatial model protection. Notably, urbanization positively influenced AWUE in neighboring regions by raisin farmer awareness about water saving practices. Similarly, Ahmed et al., (2023) conducted two years field experiment (2018-19) on cotton farms in Pakistan. The study evaluated the impact of different irrigation levels (50 % and 100 % of available water content) on cotton varieties (CIM-343, CYTO-510, CRIS-613, and CIM-678). Using time Using time-domain reflectometry (TDR-200) to monitor soil moisture, the researchers found that careful water management can maintain crop productivity even under water stress conditions in arid regions, minimizing yield losses. All of previous studies (Lu, et al., 2022; Nasir, et al., 2021; Javed, et al., 2020; USDA 2019; Imran, et al., 2019; Safitri et al., 2018; Velasco-Muñoz, et al., 2018; Shuli, et al., 2018; Cosentino, et al., 2015; Hoekstra, 2013; Jeswani, et al., 2011; Rajan, et al., 2010; Sunding, 2005) have proved a strong link between crop water use efficiency in provincial or national GDP growth.

The literature review discloses that farmer carefully considers the availability of water and land resources when making decision. Moreover, agriculture production significantly influenced by population growth, land use, and the farmers education level. Notably the choice of irrigation technology impacts demand for crop, since the cotton is a water-intensive crop, and its water demand has ranked 3rd after the sugarcane and rice. But date none of the previous study has specifically examined cotton crop water use efficiency in the context of Sindh and Punjab. So, the study is a contribution concerning cotton water use efficiency by considering socioeconomic and geo spatial factors and related policy implications.

3. Conceptual Framework

The concept of natural resource use efficiency (NRUE) was first introduced by Sprengel in (1826, 1827), who defined it as the ratio of output to input. Liebig (1840) presented the law of the optimum, which states that the optimal supply rate and ratio of inputs maximize output , (Riddiford, 2021; Liebig, 2006). The concept has been widely applied in agriculture, ecology, and environmental sciences[1]. For this study the Cobb Douglas production function is used to develop an empirical model.

$$Y = f\,(A, R, W, K) \quad (1)$$

1. Y= Out Put (Yield Kg Per Acer)
2. A= Technological Advancement (TFP)
3. R[2]= Natural resources (land area under the crop cultivation, temperature, rate of precipitation)
4. W= Water
5. K= Capital (Spending on Fertilizer, Government Spending on the Improvement of Infrastructure).

The above given Cobb Douglas production function in equation no 1 is used as a base model equation to calculate water use efficiency (WUE), by employing the common measure of NRUE in agriculture[3]. The WUE variable has been generated as the dependent variable for the study and has been used as a function of other factors. Such as the ratio of yield (Y) to water inputs, and substituted it into the original production function to obtain:

$$Y: WUE = (A * R^\wedge\alpha * W^\wedge\beta * K^\wedge\gamma) \,/\, W. \quad (2)$$

Simplified:

$$WUE = A * R^\wedge\alpha * W^\wedge(\beta - 1) * K^\wedge\gamma \quad (3)$$

In this revised function, WUE is now the dependent variable, and the independent variables are:

1. A: Technological Advancement
2. R: Natural Resources (land, temperature, precipitation)
3. K: Capital (fertilizer, infrastructure)
4. The coefficient (β-1) now reflects the elasticity of WUE with respect to water input.

Finally, it becomes:

[1] NRUE is an important concept for sustainable development, as it allows us to produce more goods and services with fewer resources.

[2] Land (area of land "A" under crop cultivation), temperature, and precipitation belong to the class of natural resources, and these denotes by "R" in to the production function equation no 1.

[3] The author has presented the standard Cobb-Douglas production function where yield (Y) is the dependent variable: Y = A * R^α * W^β * K^γ
WUE as Dependent Variable.

(W): WUE = Y / W ……………………………………………………………(4)

$WUE = (Crop\ yield) / (Water\ applied)$……………………………………(5)

This formula is derived from the work of Briggs and Shantz (1912), who were early pioneers in the field of plant physiology. Since then, many prior studies (Ngobeni, and Muchopa, 2022; Dhital, et al., 2018; Jones, 2004) have used water use efficiency as a key determinant to evaluate the benefits of applied water through economic crop production because it measures obtained output from a given input.

3.1 Calculation of Water Requirement for Cotton Crop

The following formula of water use efficiency is used to measure the WUE of cotton crop over the years from 1975 to 2022.

1. WUEc = Water Use Efficiency for Cotton
2. Y = Yield Kg Per Acer
3. W = Water Requirement for Cotton Crop (mm)
4. WUEc $= \frac{y}{w}$……………………………………………………………(6)

4. Research Methodology

4.1 Stationarity Unit Root Test

The Philips-Perron test for time series unit root test (Biometrika, 75 (1998) page no 33-46) has been used to estimate the long-run and short-run variance of the series over the years. The test considers the non-parametric approach of serial correlation and tests the null hypothesis that the series is integrated at I(I) order, and level (Iqbal, et al., 2021)[4].

$wuec\eta t = \Upsilon + \propto t + \rho wuect - 1 + \mu t$ *drift with linear trend……………… (7)*

Hypothesis

1. H_O: ρ= 1, ρ1=ρ2=ρ3=ρ4=ρ5 (Not Stationary, No Cointegration)
2. H_1: ρ < 1, ρ1=ρ2=ρ3=ρ4 =ρ5 ((Stationary, Cointegration)

4.2 Model Specification

After the stationarity test (unit root test of univariate series) the study used the widely recognized approach for time series analysis the autoregressive distributed lag (ARDL) model. The regression technique is considered appropriate when the variables are stationary at their level I (0) and integrated at the difference I (I). Since the statistical regression model generates short-run and long-run elasticities for large and small sample sizes and meanwhile follows the ordinary least square (OLS) method for cointegration among the variables, (Nasrullah, et al., 2021; Duasa, 2007; Afriyie, et al., 2020; Narayan, and Smyth, 2006).

The dependent and explanatory variables in the following model has been regressed separately for each province to get more precise results.

For long run:

$WUEc\eta_{it} = \beta o + ¥\, T1_{it} + \alpha\, T2_{it} + \Upsilon P_{it} + \phi Ed_{it} + ϘA_{it} + \chi Pd_{it} + \dot{\alpha} Cw_{it} + £Ge_{it} + \infty w_{it} + \alpha WP_{it} + \oint F_{it} + \varepsilon_{it}$……………………………………………(8)

For short run:

$\Delta wuec\eta i - t =_{i,=} \beta_{\circ} + \sum_{i,=t}^{t} \emptyset \Delta wuec\eta i =_{t-i,} \sum \sum_{i,j=t}^{t} \chi T1 + \sum_{i,-t}^{t} \gamma T2_{i,-t} + \sum_{i,-t}^{t} \partial Pt_{i,-t} + \sum_{i,j-t}^{t} \propto CW_{i,-t} + \sum_{i,-t}^{t} \forall F_{i,-t} + \sum_{i-t}^{t} \omega A_{i,-t} + \sum_{i,-t}^{t} \tau l Ge_{i,-t} + \sum_{i,-t}^{t} \gamma CW_{i,-t} + \sum_{i,-t}^{t} \psi E_{i,-t} + \sum_{i,-t}^{t} \kappa Pd_{i,-t} \sum_{i,j-t}^{t} WP\ i, -t + \varepsilon_t$ ……………………………………………(9)

[4] The (PP) unit root test is different from the ADF test specifically concerning serial correlation and heteroskedasticity in the errors.

B, ¥, α, ϒ, ϕ, Ϙ, χ, ἀ, £, χ, ∞, ∲ are long-run parameters in the above-mentioned equation 8, whereas equation 9 is for a short run which included βo, as a drift component ∅, χ, γ, ∂, ∝, ∀, ω, τ, γ, ψ, κ, ε are short-run parameters. In addition to this" ***i***" is for province "t" is for time phenomenon.

$ECTi - t$ *is the error term* which disclose the value of convergence from short run to long run. Its coefficient value must be between 0-1, though some studies have suggested that it can be between (-1 to -2), (Ibrahim, et al., 2011; Phillips, and Perron, 1988).

Table 1: Variables for the Study

	Dependent Variable:	
1	WUEc	water use efficiency for cotton (for Punjab and Sindh)
	Independent Variables:	
2	T1	Minimum temperature for the cotton-producing zones in province I, in year t
3	T 2	Maximum temperature for the regions which are cotton-producing zones in i province I, in year t
4	P	Rainfall for the cotton-producing zones in province i, in year t
5	A	Total cropped area for cotton in province I in year t
6	GE	Government expenditure on infrastructural development in million rupees (each province (Sindh and Punjab)
7	E	Primary school enrollment in province I in year t
8	F	Fertilizer consumption in province I, in year t
9	Pd	Population density in province I, in year t
10	CW	Canal water with drawl for each province at the rim station (in Kharif season), i province, year t
11	WP	Water pricing for j crop i province I and in year t).
12	Ɛt	Error term.

4.3 Data Collection

Table 1, depicts the dependent and independent variables for the study, the study has incorporated all of the important factors that are responsible for determining the water use efficiency in cotton production in Punjab and Sindh. Time period for the study is from 1976 to 2022 over the year. The water use efficiency variable is obtained by using the formula of farm field water use efficiency in above given equation no (5). The other variables data is obtained from the economic survey of Pakistan (2023); the climatic variable data is taken from the meteorological department of Pakistan, and socio-economic variable data is collected from the provincial development statistics (Sindh and Punjab), and agricultural data is taken from agricultural statictics of Pakistan (2023), for over the period of 1976 to 2022. All of the variables are chosen after literature review of the studies (Soylu, and Kızıldeniz, 2024; Arslan, 2024; Dou, et al., 2024; André et al., 2024; Shah et al., 2024; Karri and Nalluri, 2024; Zaïm, et al., 2024; Wei, et al. 2020; Frederick, et al. 2019; Cororaton, and Orden, 2008).

5. Empirical Results and Discussion

5.1 Unit Root Test

The PP test corrects the T-estimation of $\propto coeffecient$ from the AR (I) regression. It robustly considers any serial correlation and heteroskedasticity in the error term of μt. The critical values for the PP test are the same as ADF values. (Gil-Alaña, and Robinson, 1997; Usman, et al., 2021), the following unit root test, the Newy test has used the 3 user specified lags.

Table 2, presents the results of the unit root test conducted for the univariate time series analysis accordance to the literature review (Ahmad, et al., 2023; Unakitan, and Türkekul, 2014). The variables for water use efficiency (WUEC) in Punjab and Sindh are found stationary at both the level and integrated order. The minimum temperature series (T1), canal water withdrawal (CW), and fertilizer consumption (F) are stationary at order, in addition to their first difference or integrated order. Furthermore, land use, specifically the area under the crop (A), and primary school enrollment (E) in Sindh are stationary at the level and integrated order. On the other hand, population density (Pd), water prices (Wp), government expenditure on development (Ge), and maximum mean temperature (T2) are stationary for two of the provinces. In addition, primary school enrollment (E) and the area under the cotton crop in Punjab are stationary at integrated order. In summary, some variables are stationary at order (level), while others are in their integrated order with drift and trend (Maddala, and Wu, 1999). Therefore, the unit root test rejects the null hypothesis because the long-term relationship among the factors of IWRM is stationary, as some variables are stationary at level and others areon their integrated (first difference) order.

Table 2: Unit Root Test

	Sindh			**Punjab**		
Var	level	First difference	decision	level	First difference	decision
WUEc	-5.19(0.00)	-11.51(0.00)	I(0)	-3.57(0.04)	-13.74(0.00)	I(0)
T1	-4.52(0.00)	-26.74(0.00)	I(0)	-4.41(0.01)	-20.36(0.00)	I(0)
T2	-3.13 (0.11)	-20.78(0.00)	I(I)	-5.44(0.00)	-14.16(0.00)	I(I)
E	-6.74 (0.00)	-45.65(0.00)	I(0)	-2.01(0.58)	-7.14(0.00)	I(I)
A	-4.80(0.00)	-12.03(0.00)	I(0)	-1.10(0.71)	-8.02(0.00)	I(I)
Pd	-1.05 (0.93)	-4.70(0.00)	I(I)	-1.40(0.85)	-2.24(0.054)	I(I)
Wp	-2.69 (0.24)	-6.30(0.00)	I(I)	-2.26(0.44)	-7.01(0.00)	I(I)
Ge1	0.30(1.00)	-7.87 (0.00)	I(I)	-1.87(0.65)	-3.72(0.03)	I(I)
F	-3.44(0.06)	-9.41(0.00)	I(0)	-5.85(0.00)	-20.76(0.00)	I(0)
CW	-4.78(0.00)	-12.75(0.00)	I(0)	-7.19(0.00)	-14.05(0.00)	I(0)
P	-0.64(0.97)	-16.45(0.00)	I(I)	-8.56(0.00)	-38.17(0.00)	I(0)

Note: The probability values are in parenthesis.

Table 3: Bound Test

Sindh			**Punjab**		
Test (Statistic)	Value	K	Test (Statistic)	Value	K
F-statistic	7.004704	10	F-(statistic)	4.126017	10
Critical Values Bound					
Significance	I0 Bound	I1 Bound	Significance	I0 Bound	I1 Bound
0.1	1.83	2.94	0.1	1.83	2.94
0.05	2.06	3.24	0.05	2.06	3.24
0.025	2.28	3.5	0.025	2.28	3.5
0.01	2.54	3.86	0.01	2.54	3.86

Table 3 presents the results of the bound test. The bound test is commonly employed in conjunction with autoregressive distributed lag (ARDL) models, enabling the examination of short-run and long-run dynamics between variables. According to the literature, the ARDL bound test is suitable for empirical analysis of water use efficiency (Sarkodie et al., 2019; Pesaran et al., 2001). The computed f-statistic value for Sindh is 7.004, exceeding both the lower and upper critical bounds. Similarly, for Punjab, the f-statistic value is 4.126, surpassing the critical limits. Consequently, the bound test results suggest the rejection of the null hypothesis, indicating the existence of a long-run relationship between the explanatory and dependent variables, namely, water use efficiency of the cotton crop (Cook, et al., 2006; Bednarz, et al., 2002). The consistent estimates obtained from the bound test validate the research questions of the study.

Table 4: Long-run Cointegration Results

	Punjab			Sindh		
	Long Run Coefficients					
Variable	**Coefficient**	**t-Statistic**	**Prob.**	**Coefficient**	**t-Statistic**	**Prob.**
C	0.1921 (0.248)	0.776	0.447	0.3870 (0.233)	1.662	0.114
T1	-0.0161 (0.005)	-3.019**	0.007	0.0014 (0.002)	0.685	0.502
T2	0.0183 (0.009)	2.029*	0.055	-0.0016(0.005)	-2.319*	0.075
P	-0.0026 (0.001)	-2.82*	0.01	-0.0007((0.000)	-3.647**	0.002
WP	0.0001 (0.001)	0.256	0.8	-0.0014 (0.001)	-2.437*	0.025
PD	0.0022(0.000)	2.521*	0.086	0.0002 (0.000)	2.582*	0.068
GE1	0.000(0.000)	-0.49	0.629	0.0000 (0.000)	2.278*	0.035
F	0.0000 (0.000)	1.068	0.298	0.0002 (0.000)	2.455*	0.025
E	0.0001 (0.000)	2.574*	0.072	0.000 (0.000)	2.299*	0.034
CW	-0.0106 (0.006)	-4.715**	0.001	-0.0074 (0.002)	-3.235**	0.005
A	0.0000 (0.000)	0.369	0.716	0.0000 (0.000)	-0.739	0.469
CointEq(-1)	-0.5898 (0.179)	-3.301**	0.003	-0.99 (0.167)	-5.922***	0

Note: St. Error are in parenthesis, Probability values are significant at 1*** % (0.01 highly significant), 5** % (0.05 moderately significant), and 10* % (0.1 less significant). t-values are in parenthesis.

The above-given table, 4, depicts the results of long-run cointegration of dynamic autoregressive distributed lag (ARDL) long-run cointegration model, (Mujtaba, et al., 2022). The environmental component consists of climatic variables which show that the minimum temperature (T1, -0.0161), average rate precipitation (P, -0.0026(Punjab), -0.0007(Sindh) in both the provinces[5] are illustrating a negative and significant relationship with water use efficiency. Whereas in Sindh T2(maximum temperature coefficient value is significant though negative (-0.0016), and water pricing (WP, -0.00014 (Sindh) is showing significantly negative trend in terms of WUEc. Conversely, maximum temperature is showing positive and significant (T2, 0.0183) trend per acer in Punjab.

In Pakistan, the cotton crop is mainly grown on the fertile lands of Punjab and Sindh around the catchment area of the river Indus. In Punjab, the cotton crop is cultivated on the plane lands of Sargodha, Lahore, Faisalabad, Multan, Bahawalpur, and khanpur. Compared to Punjab, in Sindh's province, the crop grows on the plane lands of Rohri, Sukkur, Badin, Nawab shah, Jacobabad, and Hyderabad (Moncaleano, et al. 2021; Anjum, and Zia, 2020; Bhatti, and Soomro, 1998). All these areas are located around the catchment area of the river Indus and its major tributaries. In case of any natural calamity (unprecedented rainfall, drought, and flood) damages occur and this leads to significant farm input losses. Population density (Pd 0.0022,Punjab), 0.0002 -Sindh)), is significantly increasing with with a population exceeding 200 million. Due to given population pressure Pakistan's per capita water availability has substantially decreased over the years, currently, it has reached 908 cubic meters in 2022 then to 5650 in 1951. A noticeable point is that by end of 2006, the water table had already declined to 7 meters, due to extensive groundwater abstraction and limited surface water, (Akram, 2013).

Moreover, the increasing population density per square km is showing a negative trend because as population size increases per Anam it puts the pressure on natural resources downward. Government expenditure (Ge) on infrastructural development in Sindh and Punjab, besides fertilizer consumption (F,0.0002 (Sindh), Primary school enrollment (E), coefficients values exhibit positive and significant trend, indicating even a marginal increase in these structural and socio-economic development variables can potentially increase the water use efficiency in these two provinces of Pakistan. Notabley, government investment is a crucial and contextual determinant of water governance as it encompasses government spending on improveming of institutional capacity, technical knowledge, infrastructural development, and preparedness for risk reduction and natural calamities, (Lu, et al., 2022; Mpanga, and Idowu, 2021). However, canal water with drawl (CW,

[5] Sindh and Punjab

-0.0106 (Punjab), -0.0074 (Sindh) exhibits a negative coeefecient in both provinces. The Cointeq value (ECT) speed of adjustment from short run to long run is also significant and negative in two of the provinces, (-0.5898 (Punjab), -0.99(Sindh)). The results of the long run cointegration panel regression indicate that water is not being consumed effeciently at the farm gate . This issue requires immediate attention , particularly in the face of current climatic stress. As mentioned by (Wajid, and Salita, 2023; Prakoso, 2022; Astuti, and Khasanah, 2020; Sumedi, et al., 2021; Briliant, 2020).

5.2 Short-run ARDL Results Error Correction Model (ECM)

The error correction model (ECM) incorporates the short run results which reflects the impact of prior period's deviation from long-term equilibrium on short-run dynamics. (Fang, and Yang, 2023; Ren, and Zhong. 2020).

Table 5: Error Correction Model (ECM)

Variable	Punjab			Sindh		
	Coefficient	t-Statistic	Prob.	Coefficient	t-Statistic	Prob.
D (WUEC (-1))	-0.230(0.140)	-1.647	0.114			
D(T1)	-0.003(0.002)	-1.581	0.129	-0.262(0.143)	-1.837*	0.083
D(T2)	-0.002(0.002)	-0.975	0.341	0.001(0.002)	0.667	0.513
D(T2(-1))	-0.008(0.002)	-3.779**	0.001	0.006(0.003)	1.903*	0.073
D(P)	-0.001(0.000)	-2.484*	0.022	0.008(0.003)	2.243*	0.038
D(WP)	-0.001(0.000)	-2.431*	0.024	0.000(0.000)	-2.283*	0.035
D(WP(-1))	-0.001(0.000)	-4.202***	0	0.000(0.001)	0.255	0.801
D(PD)	0.000(0.000)	0.543	0.593	0.001(0.001)	1.359	0.191
D(GE1)	-0.000(0.000)	-3.013**	0.007	-0.008(0.004)	-1.768*	0.094
D(F)	0.000(0.000)	1.085	0.29	0.000(0.000)	3.26**	0.004
D(F(-1))				0.000(0.000)	-2.475*	0.024
D(E)	0.000(0.000)	1.489	0.151	0.000(0.000)	-6.201***	0
D(CW)	0.003(0.001)	1.976*	0.061	0.000(0.000)	1.946*	0.068
D (CW (-1))	0.005(0.001)	3.561**	0.002	-0.002(0.002)	-0.976	0.342
D(A)	0.000(0.000)	0.349	0.731	0.000(0.000)	-2.697*	0.015

Note: St. Errors values are in parenthesis. The significance level is at 10 %, (0.01) *, 5 % (0.005) **, and 1 % (0.000). the t values are in parentheses ***

The above-given table 5, shows that current year water use efficiency is negatively cointegrated with its lag value in relation to Punjab (minimum temperature (T1), maximum temperature (T2, T2(-1), average rate of precipitation (P), water prices (Wp), Wp (-1), in the short run. Conversely the minimum temperature (T1), maximum temperature (T2), T2(-1), average rate of precipitation (P), are exhibiting positive and significant trends in Sindh. Government expenditure (Ge), canal with drawl (CW), CW (-1) are significantly positive with reference to Punjab. This implies that canal water withdrawal in the kharif season has significant relationship with the dependent variable, in contrast to its lagged value. Fertilizer consumption (F) depicts positive and significant trends in the context of Sindh. (Zahid, et al. 2019; Tirlapur, et al., 2017). Government expenditure (Ge), on infrastructural development is positive and significant in the short run-in relation to WUEC. Population density (Pd), Primary school enrollment (E), also exhibits a positive relationship with WUEc in the short run. However, minimum temperature (T1), in Sindh, shows a converse but significant relationship with WUEc. The remaining variables are depicting insignificant and t mixed trends concerning the province. These results support the notion that climate change poses a real threat in the short run due to seasonal effects. (Vijayasarathy, and Ashok, 2015; Arumugam, et al. 2014; Maysami, and Koh, 2000). In a nutshell, the short run or vector error correction results are exhibiting similar tends as like long run cointegration results. The lag order is selected on the basis of Akaike (AIC) and Schwarz criteria

Table 6: Goodness of fit

Measures	Coefficient value Punjab	Coefficient value Sindh
R-squared	0.92	0.97
Adj R-squared	0.81	0.93
F-statistic	24.5	8.1
AIC	-5.5	-4.9
BIC	-4.4	-3.8
HQC	-5.1	-4.5
DWS	2.6	1.97

The table 6, provides the results of the R^2 metrics value for Sindh (0.97) and Punjab (0.92) is explaining the outcomes of more than 90 %. It is followed by adjusted R^2 which is similar for both provinces concerning cotton crop water use efficiency (0.93 (Sindh), (0.813(Punjab). Furthermore, the results are showing that model has very low AIC, and SC values, which means that the model is best fitted. The f-statics is also depicting that model is appropriate because the probability value of f-statistics is significant at 1%, low Durbin-Watson statistics also falls in the critical range and demonstrates that there is no autocorrelation exists among the variables because it is (2.6) for Punjab, and (1.97) for Sindh. In nutshell, overall model results are well estimated and there is no auto correlation and Heteroskedasticity, the diagnostic test results of overall model selection are given below in table 7 and 8.

Table 7: Diagnostic Serial Correlation Test

Punjab			
Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.62	Prob. F(2,19)	0.22
Obs*R-squared	6.54	Prob. Chi-Square (2)	0.04
Sindh			
F-statistic	0.51	Prob. F(2,16)	0.61
Obs*R-squared	2.69	Prob. Chi-Square (2)	0.26

Table 8: Heteroskedasticity Test

Punjab			
Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	1.5	Prob. F(27,17)	0.19
Obs*R-squared	31.7	Prob. Chi-Square (27)	0.24
Scaled explained SS	4.0	Prob. Chi-Square (27)	1
Sindh			
F-statistic	1.11	Prob. F(26,18)	0.42
Obs*R-squared	27.71	Prob. Chi-Square (26)	0.37
Scaled explained SS	9.03	Prob. Chi-Square (26)	1.00

6. Conclusion

The results of empirical analysis of Autoregressive distributed lag (ARDL) model, long term cointegration findings disclosed that that population density per square km is truly getting momentum. This pressure is degrading the ecology and ecosystem of the provinces in Pakistan (especially Sindh and Punjab), particularly in relation to long-term economic stability in the country water resources management. Therefore, in given situation textile sector is on high risk due to uncertainty of climate change and its subsequent effect on cotton water farm use efficiency, there is a significant gap exist between policy and practice in the country. Even though the planned government expenditure is significantly aligned with the agriculture growth in the country. However, it is essential that without any further delay the development objectives of agriculture need to prioritize as per socioeconomic changes. By doing this government can achieve sustainable agricultural growth in the short run and in the long run in relation to improving cotton crop productivity in the provinces. Moreover, smart water use management practices demand technical knowledge and well-equipped human resources because the agriculture and irrigation farm use practices are highly sensitive to human technical knowledge.

In the end the study proposed that, more and advance research is required to investigate the link between population density and environmental degradation assessing the textile sector's climate change vulnerability. Since the integration of integrated water resource management education is also essential at grass root level for to develop long-term sustainable water management strategies. Therefore, smart farm water management practices and policies need to be adapted, for the implementation of these more investment is needed on technology and innovation. Therefore, more investment on small dams, nature-based solutions and watershed development in rural areas is needed by developing long term sustainable water management strategies.

Acknowledgement.
The author acknowledges the useful comments from the Editor and anonymous reviewers. Moreover, all remaining errors are our own.

Data Availability Statement.
Data is self-collected from published (secondary sources) and self-regressed and will be provided on demand.

Funding if any:
This research has received no external funding.

Conflict of Interest Disclosure statement:
There is no conflict of interest among the authors of the study.

Ethical Approval:
Ethical approval has been taken from the relevant forum if necessary.

References

Abbas, S. (2020). Climate change and cotton production: an empirical investigation of Pakistan. *Environmental Science and Pollution Research*, *27*(23), 29580-29588.

Afriyie, J. K., Mensah, I. K., Ofori, E. K., and Osei, E. K. (2020). Evaluating the Performance of Unit Root Tests in Single Time Series Processes. *Mathematics and Statistics*, 8(6), 656–664.

Ahmad, S., Ahmad, I., Ahmad, B., Ahmad, A., Wajid, A., Khaliq, T., ... And Hoogenboom, G. (2023). Regional integrated assessment of climate change impact on cotton production in a semi-arid environment. *Climate Research*, *89*, 113-132.

Ajani, A., and van der Geest, K. (2021). Climate change in rural Pakistan: evidence and experiences from a people-centered perspective. *Sustainability Science*, *16*, 1999-2011.

Akram, A. A. (2013). Is a surface-water market physically feasible in Pakistan's Indus Basin Irrigation System? *Water International*, 38(5), 552-570.

Ali, G., Ashraf, A., Bashir, M. K., and Cui, S. (2017). Exploring environmental Kuznets curve (EKC) in relation to green revolution: a case study of Pakistan. *Environmental Science and Policy*, *77*, 166-171.

Ali, M. A., Anjum, S. A., Hussain, S., Ali, M., and Anjum, M. A. (2019). Cotton production in Pakistan. In Cotton Production (pp. 249-276). Springer.

André, F. J., Buendía, A., and Santos-Arteaga, F. J. (2024). Efficient water use and reusing processes across Spanish regions: A circular data envelopment analysis with undesirable inputs. *Journal of Cleaner Production*, *434*, 139929.

Anjum, A., & Zia, U. (2020). Unravelling water use efficiency in sugarcane and cotton production in Pakistan. *The Pakistan Development Review*, *59*(2), 321-326.

Arslan, F. (2024). Production-water user association performance nexus in mediterranean irrigated agriculture: The case of banana in Türkiye. *Agricultural Water Management*, *292*, 108650.

Arumugam, S., et al. (2014). Does Climate Variability Influence Yield of Major Crops? -A Case Study of Tamil Nadu. *Agricultural Economics Research Review,* 27(1), 61-71.

Ashraf, S., Sangi, A. H., Hassan, Z. Y., and Luqman, M. (2018). Future of cotton sector in Pakistan: A 2025 Outlook. *Pakistan Journal of Agricultural Research, 31*(2).

Astuti, P. B., and Khasanah, N. (2020). Determinants of Indonesia's National Income: An Auto-Regressive Distributed Lag Analysis. Signifikan: *Jurnal Ilmu Ekonomi*, 9(2), 207-218.

Barros, A. P. (2013). Orographic Precipitation, Freshwater Resources, and Climate Vulnerabilities in Mountainous Regions. In Climate Vulnerability (pp. 57-78). Elsevier.

Bednarz, C. W., Grichar, W. J., and Kelley, J. (2002). Cotton crop water use and irrigation scheduling. In AS Culpepper (Ed.), Proceedings of the Beltwide Cotton Conference (pp. 61-64). National Cotton Council of America.

Bhatti, M. A., and Soomro, A. R. (1998). Farmers' Perspectives on Warah Branch Canal Operations.

Briggs, L. J., and Shant, H. (1912). Thus, the experimental work of gain, heinrich, hedgcock. *Botanical Gazette*, *53*, 229.

Briggs, L. J., and Shantz, H. L. (1913). The water requirement of plants (No. 284-285). US Government Printing Office.

Briliant, D. (2020). Rupiah's Overshooting Phenomenon. *Journal of Research in Business, Economics, and Education*, 2(4), 731-741.

Chaudhary, M. T., Majeed, S., Rana, I. A., Ali, Z., Jia, Y., Du, X., ... And Azhar, M. T. (2024). Impact of salinity stress on cotton and opportunities for improvement through conventional and biotechnological approaches. *BMC Plant Biology*, *24*(1), 20.

Cook, S., Gichuki, F., and Turral, H. (2006). Agricultural Water Productivity: Estimation at plot, farm and basin scale (No. 618-2016-41140).

Cororaton, C. B., & Orden, D. (2008). *Pakistan's cotton and textile economy: Intersectoral linkages and effects on rural and urban poverty* (Vol. 158). Intl Food Policy Res Inst.

Cosentino, C., Adduci, F., Musto, M., Paolino, R., Freschi, P., Pecora, G., ... & Valentini, V. (2015). Low vs high "water footprint assessment" diet in milk production: A comparison between triticale and corn silage-based diets. *Emirates Journal of Food and Agriculture*, *27*(3), 312-317.

Dhital, B., et al. (2018). The absence of restricted water pool in brain white matter. Neuroimage, 182, 398-406.

Dong, H., Geng, Y., Fujita, T., Fujii, M., Hao, D., and Yu, X. (2014). Uncovering regional disparity of China's water footprint and inter-provincial virtual water flows. *Science of the total environment*, *500*, 120-130.

Dou, X., Yu, G., Chen, Z., Yang, M., Hao, T., Han, L., ... And Zhou, W. (2024). High spatial variability in water use efficiency of terrestrial ecosystems throughout China is predominated by biological factors. *Agricultural and Forest Meteorology*, *345*, 109834.

Duasa, J. (2007). Malaysian foreign direct investment and growth: does stability matter? *Journal of Economic Cooperation Among Islamic Countries*, *28*(2).

Falkenmark, M., and Rockström, J. (2006). The new blue and green water paradigm: Breaking new ground for water resources planning and management. *Journal of Water Resources Planning and Management*, 132(3), 129-132.

Fang, X., and Yang, N. (2023). A Neural Learning Approach for a Data-Driven Nonlinear Error Correction Model. *Computational Intelligence and Neuroscience*, 2023, 5884314.

Fatima, Z., Ahmad, N., and Imran, R. (2024). Impact of Income Inequality and Population Density on Carbon Emissions in Pakistan. *Journal of Economic Sciences, 3*(1), 103–120.

Fazeli, M., Hamidi, A., Esmaeilzadeh, F., Dowlati, M., Azizi, K., and Mostafavi, E. (2018). Design and validation of a Persian Knowledge, Attitude, and Practice Questionnaire for Rabies (PKAP-Rabies) in the general population of Iran. *Journal of Medical Microbiology and Infectious Diseases*, 6(2), 67-71.

Frederick, S., et al. (2019). Pakistan in the Apparel Global Value Chain. Duke Global Value Chains Center.

Gil-Alaña, L. A., and Robinson, P. M. (1997). Testing of Unit Root and Other Nonstationary Hypotheses in Macroeconomic Time Series. *Journal of Econometrics*, 80(2), 241–268.

Hatfield, J. L., and Dold, C. (2019). Water-use efficiency: Advances and challenges in a changing climate. *Frontiers in Plant Science*, 10, 103.

Hoekstra, A. Y., and Hung, P. Q. (2005). Globalisation of water resources: International virtual water flows in relation to crop trade. Global Environmental Change: Human and Policy Dimensions, 15(1), 45-56.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., and Mekonnen, M. M. (2011). The water footprint assessment manual: Setting the global standard. Routledge.

Ibrahim, J., Fatai, K., and Azeez, B. A. (2011). Weak-Form Efficiency of Foreign Exchange Market in the Organization for Economic Cooperation and Development Countries: Unit Root Test. *International Journal of Business and Management*, 6(6). Https://doi.org/10.5539/ijbm.v6n6p55.

Imran, M. A., Ali, A., Ashfaq, M., Hassan, S., Culas, R., and Ma, C. (2019). Impact of climate smart agriculture (CSA) through sustainable irrigation management on Resource use efficiency: A sustainable production alternative for cotton. *Land Use Policy, 88*, 104113.

Iqbal, R., Raza, M. A. S., Rashid, M. A., Toleikiene, M., Ayaz, M., Mustafa, F., ... & Haider, I. (2021). Partial root zone drying irrigation improves water use efficiency but compromise the yield and quality of cotton crop. *Communications in Soil Science and Plant Analysis*, *52*(13), 1558-1573.

Iqbal, R., Firdous, A., Hyder, S., Valipour, M., Zaheer, M., Iqbal, J., ... & El Sabagh, A. (2024). Optimizing deficit irrigation and soil mulch adaptation strategies for cotton (gossypium hirsutum l.) Productivity and economic gains under water-limited dry climatic conditions. *Applied ecology & environmental research*, *22*(1).

Iqbal, Z., Ahmad, I., Anwar, M., Ali, A., and Naveed, K. (2023). Evaluation of genetic variability for different fiber and yield related components in cotton (Gossypium hirsutum L.). *Biological and Clinical Sciences Research Journal*, 2023(1), 177-177.

Jamil, I., Jun, W., Mughal, B., Waheed, J., Hussain, H., and Waseem, M. (2021). Agricultural Innovation: A comparative analysis of economic benefits gained by farmers under climate resilient and conventional agricultural practices. *Land Use Policy*, *108*, 105581

Janjua, S., and Hassan, I. (2020). Use of bankruptcy methods for resolving interprovincial water conflicts over transboundary river: Case study of Indus River in Pakistan. *River Research and Applications*, 36(7), 1334-1344.

Javed, A., Iqbal, M., and Shehzadi, R. (2020). Effect of Plastic Film and Straw Mulch on Wheat Yield, Water Use Efficiency and Soil Properties in Punjab, Pakistan. *Journal of Bioresource Management*, *7*(4), 5.

Javed, M. A., Rashid Ahmad, S., Awan, W. K., and Munir, B. A. (2020). Estimation of crop water deficit in lower Bari Doab, Pakistan using reflection-based crop coefficient. *ISPRS International Journal of Geo-Information*, *9*(3), 173.

Jeswani, H. K., and Azapagic, A. (2011). Water footprint: methodologies and a case study for assessing the impacts of water use. *Journal of Cleaner Production*, 19(12), 1288-1299.

Jones, H. (2004). What Is Water Use Efficiency. Water Use Efficiency in Plant Biology, pp. 27–41.

Karri, V., and Nalluri, N. (2024). Enhancing resilience to climate change through prospective strategies for climate-resilient agriculture to improve crop yield and food security. *Plant Science Today*, *11*(1), 21-33.

Khan, A., Sheikh, M. R., Ahmad, S., and Mushtaq, M. I. (2024). Climate Change Adaptation, Food Security and Livelihood: A Case Study of Multan Division. *Journal of Economic Sciences*, *3*(1), 25–56.

Kijne, J. W., et al. (2003). Ensuring food security via improvement in crop water productivity. Challenge Program on water and Food Background Paper 1, 20-26.

Lu, W., Jiang, Y., Wang, H., and Gao, Y. (2022). The impacts of urbanization to improve agriculture water use efficiency—an empirical analysis based on spatial perspective of panel data of 30 provinces of China. Land, 11(1), 80.

Maddala, G. S., and Wu, S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics*, 61(s1), 631–652.

Maysami, R. C., and Koh, T. S. (2000). A Vector Error Correction Model of the Singapore Stock Market. *International Review of Economics and Finance*, 9(1), 79-96.

Moncaleano, Callejas, S., Salcedo, S., and López-López, E. (2021). Water Use Efficiency: A Review of Contextual and Behavioral Factors. *Frontiers in Water*, 3.

Mpanga, I. K., and Idowu, O. J. (2021). A Decade of Irrigation Water Use Trends in Southwestern USA: The Role of Irrigation Technology, Best Management Practices, and Outreach Education Programs. *Agricultural Water Management*, 243, 106438.

Muhammad, M., Hussain, A., Ali, S., Akram, W., Roomi, I., Faiz, F., and Hussain, I. (2022). Geostatistical Analysis of Apricot Shot Hole Disease and Influence Factors in District Nagar, Gilgit-Baltistan, Pakistan. *International Journal of Phytopathology*, *11*(3), 227-238.

Mujtaba, A., Akhtar, M., Khalid, M., and Ullah, A. (2022). Impact of Cropping Pattern and Climatic Parameters in Lower Chenab Canal System—Case Study from Punjab Pakistan. *Agriculture*, 12(5), 708.

Mujtaba, G., Shah, M. U. H., Hai, A., Daud, M., and Hayat, M. (2024). A holistic approach to embracing the United Nation's Sustainable Development Goal (SDG-6) towards water security in Pakistan. *Journal of Water Process Engineering*, *57*, 104691.

Narayan, P. K., and Smyth, R. (2006). What Determines Migration Flows from Low-Income to High-Income Countries? An Empirical Investigation of Fiji-US Migration 1972-2001. *Contemporary Economic Policy*, 24(2), 332–342.

Nasir, J., Ashfaq, M., Baig, I., Khair, S. M., Mangan, T., Allan, C., Ali, A., Culas, R., & Punthakey, J. F. (2021). Representative agricultural pathways and socioeconomic benefits of groundwater management interventions in Punjab, Sindh and Balochistan Provinces, Pakistan. (ILWS; No. 161). Institute for Land, Water and Society.

Nasrullah, M., Ali, M. H., Salman, M., Shahzad, U., and Abbas, Q. (2021). An Asymmetric Analysis of the Impacts of Energy Use on Carbon Dioxide Emissions in the G7 Countries. *Environmental Science and Pollution Research International*, 28(32), 43643–43668. Https://doi.org/10.1007/s11356-021-13799-5.

Naz, A., and Kousar, S. (2024). Globalization, Environmental Kuznets Hypothesis, and COP Outcomes: Pathways to Sustainability for Developed and Developing Countries. *Journal of Economic Sciences*, *3*(2), 121–136.

Nazir, A., Lodhi, A. S., Akhtar, S., and Khajjak, A. K. (2024). Analysing The Nexus Of Weather On Cotton Production In Sindh Pakistan: Using Ardl Bound Test. *Agricultural Sciences Journal*, (1), 123-134.

Ngobeni, E., and Muchopa, C. L. (2022). The Impact of Government Expenditure in Agriculture and Other Selected Variables on the Value of Agricultural Production in South Africa (1983–2019): Vector Autoregressive Approach. *Economies*, 10(9), 205.

Pakistan Agriculture Statistics (2023). Https://www.pbs.gov.pk/content/agriculture-statistics.

Pesaran, M. H., Shin, Y., and Smith, R. J. (2001). Bounds Testing Approaches to the Analysis of Level Relationships. *Journal of Applied Econometrics*, 16(3), 289–326. .

Phillips, P. C. B. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika*.

Phillips, P. C. B., and Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika*, 75(2), 335–346.

Prakoso, D. (2022). Impact of The Global Stocks Index on The Shariah and Conventional Stocks Index in Indonesia. *Islamic Economics Methodology*, 1(1).

Government of Sindh**.** (2023). *Provincial development statistics Sindh 2023*. Retrieved from https://www.pbs.gov.pk/sites/default/files/population/2023/Sindh.pdf.

Government of Punjab, Bureau of Statistics. (2023). *Provincial development statistics Punjab 2023*. Retrieved from https://bos.punjab.gov.pk/developmentstat

Rajan, N., Krieg, D. R., and Green, T. R. (2010). Estimating crop water use of cotton in the Texas High Plains. *Agronomy Journal*, 102(6), 1641-1651.

Razzaq, A., Qing, P., Abid, M., Anwar, M., and Javed, I. (2019). Can the informal groundwater markets improve water use efficiency and equity? Evidence from a semi-arid region of Pakistan. *Science of The Total Environment*, *666*, 849-857.

Rehman, A., Hanif, M., and Javaid, U. (2019). Economic perspectives of cotton crop in Pakistan: A time series analysis (1970-2015) (Part 1). *Journal of the Saudi Society of Agricultural Sciences*, 18(1), 49-54.

Ren, X., Shao, Q., and Zhong, R. (2020). Nexus between green finance, non-fossil energy use, and carbon intensity: Empirical evidence from China based on a vector error correction model. *Journal of Cleaner Production*, 277, 122844.

Riddiford, J. (2021). Current integrated catchment management policy and management settings in the Murray–Darling Basin. *Murray-Darling Basin, Australia*, 185-201.

Saeed, M., Naeem, M., Javed, A., Perveen, S., Sajjad, I., Yousaf, M. Z., ... And Song, X. (2024). Characterization of water-deficit tolerance in Upland cotton (Gossypium hirsutum L.) Assessing morphological, biochemical, molecular and yield attributes. *Acta Physiologiae Plantarum*, *46*(1), 13.

Safitri, L., Yuniarti, K., Widyanto, S. A., and Santoso, B. (2018). Water footprint and crop water usage of oil palm (Eleasis guineensis) in Central Kalimantan: Environmental sustainability indicators for different crop age and soil conditions. *Water*, 11(1), 35.

Sarkodie, S. A., Strezov, V., and Raine, A. (2019). Environmental Sustainability Assessment Using Dynamic Autoregressive-Distributed Lag Simulations-Nexus between Greenhouse Gas Emissions, Biomass Energy, Food and Economic Growth. *The Science of the Total Environment*, 668, 318–332.

Sarwar, A., Medellín-Azuara, J., and Viers, J. H. (2024). Economics of microirrigation systems. In *Microirrigation for Crop Production* (pp. 157-173). Elsevier Science.

Sengupta, A., and Thangavel, M. (2023). Analysis of the Effects of Climate Change on Cotton Production in Maharashtra State of India Using Statistical Model and GIS Mapping. *Caraka Tani: Journal of Sustainable Agriculture*, *38*(1), 152-162.

Shah, W. U. H., Lu, Y., Liu, J., Rehman, A., and Yasmeen, R. (2024). The impact of climate change and production technology heterogeneity on China's agricultural total factor productivity and production efficiency. *Science of The Total Environment*, *907*, 168027.

Shahzad, K., Razaq, A., Ali, A., Afzal, M., and Hussain, A. (2022). Progress and perspective on cotton breeding in Pakistan. *Journal of Cotton Research*, 5(1), 1-17.

Shuli, F., Amin, M., Mengal, A., Sial, M. A., and Khan, A. R. (2018). Overview of the cotton in Pakistan and its future prospects. *Pakistan Journal of Agricultural Research*, 31(4), 396-407.

Soylu, E., and Kızıldeniz, T. (2024). Innovative approach of biodegradable mulches in sustainable agriculture for crop production and environmental conservation. In *BIO Web of Conferences* (Vol. 85, p. 01060). EDP Sciences.

Sprengel, C. (1827). Über Pflanzenhumus, Humussäure und humussaure Salze. *Archiv der Pharmazie*, 21(3), 261-263.

Stanhill, G. (1986). Water use efficiency. *Advances in agronomy*, 39, 53-85.

Sumedi, S., Akhyar, C., Matriadi, F., & Zuhra, I. (2021). The Influence of Sales Growth, Company Size and Working Capital Turnover on Company Profitability at PT. Chemical Farma of Indonesia. *The International Journal of Business & Management, 9*(11).

Sunding, D. (2005, March). The economics of agricultural water use and the role of prices. In *Water Conservation, Reuse and Recycling: Proceedings of an Iranian–Am. Workshop, Washington, DC*.

Government of Pakistan, Ministry of Finance, Economic Affairs Division. (2023). *Economic Survey of Pakistan 2023*. Government of Pakistan

Tirlapur, L. N., and Desai, N. R. M. (2017). Impact of Climate Variability on Crop Yield in Different Districts of Gulburga Division. *International Research Journal of Agricultural Economics and Statistics*, 8(1), 176-182.

Tiwari, M., Singh, A. K., and Sinha, D. K. (2015). Stable isotopes: Tools for understanding past climatic conditions and their applications in chemostratigraphy. In *Chemostratigraphy* (pp. 65-92). Elsevier.

Tokel, D., et al. (2022). Economic Impacts of Bt (Bacillus Thuringiensis) Cotton. *Journal of Natural Fibers*, 19(12), 4622–4639.

Unakitan, G., and Türkekul, B. (2014). Univariate modelling of energy consumption in Turkish agriculture. *Energy Sources, Part B: Economics, Planning, and Policy, 9*(3), 284-290.

USDA Farmer Cooperative Service. (2022). Summary of Cooperative Cases, Vol. 68: June 1956 (Classic Reprint). Forgotten Books.

Usman, M., Huang, X., Wang, Y., and Rasheed, M. I. (2021). Research and Development Spillover, Irrigation Water Use and Agricultural Production in Pakistan. *WSEAS Transactions on Environment and Development*, 17, 840–858.

Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., Belmonte-Ureña, L. J., and López-Serrano, M. J. (2018). Advances in water use efficiency in agriculture: *A bibliometric analysis*. *Water*, *10*(4), 377.

Vijayasarathy, K., and Ashok, K. R. (2015). Economic Impact of Climate Variability on Agriculture in Areas of High Climate Variability in Tamilnadu-Ricardian Approach. *Karnataka Journal of Agricultural Sciences*, 28(5), 775-779.

Wajid, A., and Salita, S. (2023). Identifying Threshold Level of Urbanization for Economic Growth in Developing and Developed Asian Economies. *Journal of Economic Sciences*, *2*(2), 113–126.

Wang, X. C., Klemeš, J. J., Wang, Y., Dong, X., Wei, H., Xu, Z., and Varbanov, P. S. (2020). Water-Energy-Carbon Emissions nexus analysis of China: An environmental input-output model-based approach. *Applied Energy*, *261*, 114431.

Wani, B. A., Rashid, S., Rashid, K., Javid, H., Magray, J. A., ul Qadir, R., and Islam, T. (2022). Nitrogen Deficiency in Plants. In *Advances in Plant Nitrogen Metabolism* (pp. 28-37). CRC Press.

Wei, W., et al. (2020). Estimating the Economic Viability of Cotton Growers in Punjab Province, Pakistan. *SAGE* Open, 10(2), 215824402092931.

Xue, J., Guan, H., Huo, Z., Wang, F., Huang, G., and Boll, J. (2017). Water saving practices enhance regional efficiency of water consumption and water productivity in an arid agricultural area with shallow groundwater. *Agricultural Water Management*, *194*, 78-89.

Zahid, K. B., et al. (2019). Relationship between Climate and Year to Year Variability in Crop Yield: Selected Districts of Pakistan. *Sarhad Journal of Agriculture*, 35(1).

Zaïm, M., Sanchez-Garcia, M., Belkadi, B., Filali-Maltouf, A., Al Abdallat, A., Kehel, Z., and Bassi, F. M. (2024). Genomic regions of durum wheat involved in water productivity. *Journal of Experimental Botany*, *75*(1), 316-333.

Zhou, B., Wang, N., Zhang, Z., Liu, W., Lu, W., Xu, R., and Li, L. (2022). Research on the Spatial-Temporal Differentiation and Path Analysis of China's Provincial Regions' High-Quality Economic Development. *Sustainability*, *14*(10), 6348.

Zulfiqar, F., and Thapa, G. B. (2021). The Effect of Cotton Management Practices on Water Use Efficiency and Water Security Challenges in Pakistan. *Water Security in Asia: Opportunities and Challenges in the Context of Climate Change*, 557-566.