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Nexus between Life Expectancy, CO_2 Emissions, Economic Development, Water, and Agriculture in Aral Sea Basin: Empirical Assessment

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Abstract: This study investigates how life expectancy is influenced by CO_2 emissions, health spending, GDP, water usage, agricultural output, and renewable and non-renewable energy consumption within the Aral Sea basin, which is an environmentally catastrophic zone in the world. This research utilized data from the years 2002 to 2020 and employed various econometric approaches, including FMOLS, DOLS, and Driscoll–Kraay. The outcomes of the study reveal that health spending, GDP, water productivity, agriculture output, energy consumption, and human capital have a positive impact on life expectancy, but CO_2 emissions have a negative impact on life expectancy. The most important policy takeaway from this study is the need to develop and implement comprehensive policies that take into account health spending, GDP, water, agricultural output, energy consumption, and education level in order to ensure life longevity.

Keywords: life expectancy; climate change; water resource management; agriculture; Aral Sea basin; economic development

1. Introduction

Access to clean water, green energy, and food are essential to ensure life expectancy and well-being. Sustainable access to and management of these resources is a foundation for long-term economic growth and ecological sustainability. A growing number of scholars have focused more on the concepts of life expectancy, environmental well-being, and the water–energy–food nexus in response to the pressing need for the efficient and balanced use of these limited resources. Indeed, the scientific community has focused particularly on the Aral Sea basin as a glaring illustration of ecological disasters caused by human activity [1]. One of the most notorious ecological disasters in history, the destruction of the Aral Sea area directly affects life expectancy in eight countries that make up the Aral Sea basin: Iran, Uzbekistan, Kazakhstan, Kyrgyz Republic, Tajikistan, Afghanistan, Turkmenistan, and Uzbekistan [2].

The United Nations defines that excessive water use is a reason for environmental catastrophe in the Aral Sea Basin (ASB) [3], where water resources are shared by the five major riparian countries of Central Asia (Uzbekistan, Turkmenistan, Tajikistan, Kazakhstan, and Kyrgyzstan), mismanagement of water resources and ineffective irrigation systems are to blame for the Aral Sea disaster [4]. The two most important resources for producing food are land and water, and they are closely related. Climate change, population increase, and increased irrigation are endangering the basin's ability to sustain development [5].

Over the last 10,000 years, there have been several water level drops and subsequent recoveries in the Aral Sea prior to the current recession [6,7]. Since 1960, the Amu Darya and Syr Darya, the Aral's two tributaries, have dried up and suffered significant damage to their deltas due to the unsustainable expansion of irrigation. This has caused the Aral to rapidly desiccate and salinate [8]. The imbalance of shared water resources available to Central Asian countries makes the Aral Sea Basin water resource system one of the most complex networks in the world. Water governance in the basin is challenging due to geopolitical concerns among these nations. To support energy production, economic expansion, and food security, each has its own national water policy [9,10]. There has been a significant change in the Aral Sea region's ecological state [11]. It has caused the climate in the area to change, irrigated soils to turn into deserts, deterioration of surface and subsurface water quality, reduction of water available for domestic and agricultural needs, loss of Aral Sea fishing and transportation importance, and a host of other issues that have ultimately put the health of current and future generations at risk [12,13]. Due to the collapse of the local fishing industries, a large number of people have moved to the irrigation sector, which, for decades, has been the only industry sector that has consistently grown [14,15]. In the former Vozrozhdeniye Peninsula in the Aral Sea, there was even a biowarfare weapons test site during the Soviet era [16]. The Aral Sea's severe desiccation accelerated the region's desertification processes and resulted in the formation of the Aralkum, a new desert on the dried-out sea floor [17].

With the aforementioned context in mind, this study aimed to establish the relationship between life expectancy at birth and the basic indicators of socioeconomic development. The novelty of the study is to investigate the potential integration of "life expectancy" factors into policies pertaining to carbon dioxide (CO_2) emissions and water productivity in Aral Sea basin countries. The objective of the research is to examine the dynamic relationship between life expectancy, environmental degradation, economic development, water, and agriculture. In this regard, we set out to answer the following two research questions: (1) In the Aral Sea region, are CO_2 emissions contributing to a diminished life expectancy? (2) Does water scarcity contribute to a reduction in the region's population's life expectancy? As far as our understanding extends, there has been no single research that has specifically examined this matter. By providing answers to these two significant questions, the current research aims to provide policy recommendations for long-term sustainable development.

2. Literature Review

2.1. Life Expectancy and CO_2 Emissions

The discharge of carbon dioxide into the atmosphere has the potential to impact human health as well as generate a number of environmental issues. The impact of CO_2 emissions on life expectancy in the D-8 countries was investigated, and the results revealed that these emissions can have a notable and adverse influence on life expectancy [18]. Examining the correlation between carbon dioxide emissions and life expectancy in 68 low and middle-income nations, a negative relationship between CO_2 emissions and life expectancy was observed across rising economies [19]. Studying the interplay between CO_2 emissions and health outcomes in the Global South, further improvement in infrastructural facilities and a reduction in CO_2 emissions are suggested to achieve a good health outcome [20]. However, Asian authorities should develop sensible and practical regulations providing enough funding for the healthcare sector [21]. Focusing on Central Asia, economic and environmental issues need to be highlighted to minimize the damaging effects of economic growth on the environment [22].

2.2. Water and Human Vulnerability in Aral Sea Basin

Since the 1960s, the nations that make up the Aral Sea basin have used water resources in an unsustainable manner, which has led to a number of issues with industry, agriculture, public health, and the environment [23]. The complexity of global, regional, and local issues, as well as massive irrigation, land-use changes, and global warming, are causing climatic and environmental changes in the Aral Sea Basin [15,24,25]. Analyzing the Aral Sea's changes from 1960 to 2018, Ref. [26] pinpointed the moment for the retreat's slowdown and investigated the underlying causes using the extreme-point symmetric mode decomposition (ESMD) method and the multiple linear regression model [26,27]. The review provides a multi-scale approach to vulnerability assessment and looks at the role of scale in assessing human vulnerability to climate change [24]. Ref. [8] explores the current efforts to restore the Aral and looks at several scenarios of the sea for the future (Figure 1), primarily using hydrologic data based on hydrologic and salinity models [8].

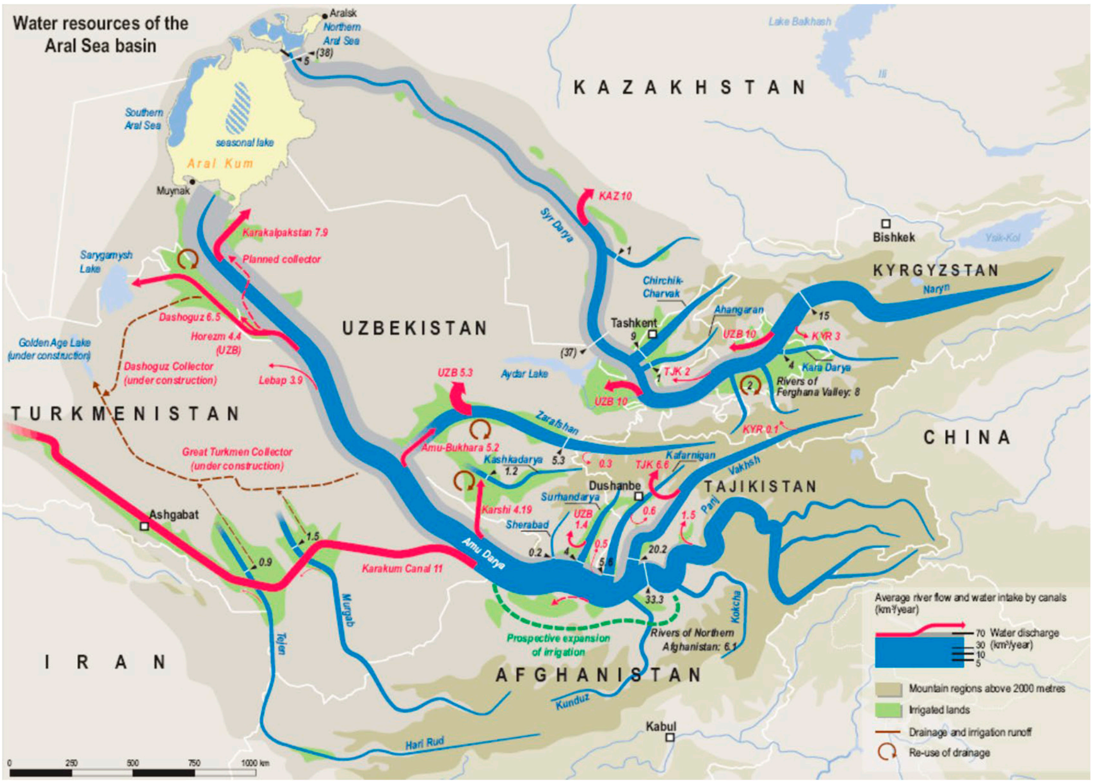

Figure 1. The Aral Sea basin. Source [28].

The Aral Sea's area was only 10.3% of its original size, and its water content was only 4.4% of what it once was [8]. As a result, the Aral Sea's salinity increased from 10 g/L in 1960 to 130 g/L by 2010 [29]. However, the Aral Sea basin has become one of the world's most heavily irrigated regions, with 5.2 million hectares of land under irrigation in 1960, rising to 9.61 million hectares by 2008 [30]. The Aral Sea has gotten smaller as a result of over-irrigation, which has also degraded the land and raised salt levels. Due to the overuse of water resources and poor upkeep of irrigation and drainage systems, more than half of the irrigated lands in the Aral Sea region have turned saline [27,30]. Thus, the formation of dust storms concentrated with pollutants and dried salt from the exposed seabed is one of the major problems associated with the Aral Sea's decline [15,26]. These particles are carried great distances by strong winds, which have a negative impact on the environment, human health, soil erosion, and desertification [15,31].

2.3. Transboundary Water Resource Management

Water has become a major source of conflict in the region, even with the comprehensive water cooperation agreement signed by Central Asian countries [32]. The Amu Darya and Syr Darya rivers provide water to about 65 million people who live in the Aral Sea basin; estimates suggest that by the end of the century, this number will have increased to about 90 million people [33]. Tajikistan provides the Aral Sea basin with about half of its water resources [16]. With a share of 29%, Kyrgyzstan ranks second in terms of water production. The main users of these resources are the downstream nations of Kazakhstan, Turkmenistan, and Uzbekistan [34].

The current irrigation techniques are unsustainable, reducing crop yield, and these practices deteriorate soil and water salinity in the Aral Sea basin [35]. The region's irrigation systems need to be rebuilt and maintained. Following contemporary irrigation guidelines is essential to achieving the best possible results [15,36]. Greater cooperation is required for sustainable management and to ensure the resilience of water resources in the area [25,37]. International organizations and funding agencies ought to serve as facilitators and mediators [32]. A scenario put forth is based in part on the utilization of Caspian water evaporators, which are situated on the Caspian Sea's eastern coast and of which Kara-Bogaz-Gol is thought to be the only operational evaporator [38]. It demonstrates that if this scenario comes to pass, the Aral Sea can be saved and Central Asia's water balance can return to normal [32]. Based on various scenario versions, the Aral Sea could be restored in 90–240 years, according to calculation results. Within a century, the Aral Sea cannot be restored with Kara-Bogaz-Gol as the only evaporator. Furthermore, the Aral Sea would replenish itself in roughly 90 years if the human runoff of river waters was reduced by 10%. Under extreme conditions and protracted dry spells, the water supply may only be able to meet half of the demand [39].

The world's largest producer of cotton is the Aral Sea basin [40]. However, due to significant agricultural expansion and ineffective drainage, water stress in the ASB has emerged as a significant ecological environment and socioeconomic concern in recent decades [15,41]. Water intake, water stress, and land degradation in downstream countries were stronger than those in the upstream countries, particularly in Karakalpakstan, Tashauz, and Karakum [42]. Thus, in the downstream regions, cropping intensity and cotton yield were significantly impacted by the water intake [38]. Nonetheless, the growth of cash crop cultivation has resulted in an unsustainable rise in water consumption for irrigation due to the cotton plants' high water requirements in the dry climate of the Aral Sea basin [43]. A sensitivity analysis was conducted to address policy issues related to investments in drip irrigation, the liberalization of cotton prices, increased crop productivity, and a mixed policy that combines these three policies [44]. It was estimated that crops only use 50% of agricultural water resources, with the remaining portion being lost during storage, conveyance, and subsurface drainage after application [45,46]. In Central Asia, in particular, water losses are up to 60% [47,48] due to antiquated infrastructure [49] and the predominance of extremely inefficient flood and furrow irrigation methods [50].

2.4. Climate Change Effects

Increased temperatures, variations in precipitation patterns, changes in the hydrological cycle, evapotranspiration, temperature swings, and changes in precipitation patterns are all brought about by climate change in the Aral Sea basin [32,51]. Due to factors like limited water resources, complex terrain, low adaptive capacity, and relatively low levels of economic and social development progress, the Aral Sea region is extremely vulnerable and resilient to the effects of climate change [24,25,52].

With the disappearance of the smaller glaciers, the average annual flow discharge will start to decrease around 2080 [53]. The Aral Sea's water supply has benefited from climate change [54]. However, the main reason the sea keeps getting smaller is the massive amount of water that agriculture uses and has been using for as long as the Soviet Union existed [42]. There are significant concerns regarding the potential mobilization of salts and heavy metals in the southern Aral Sea region, which is primarily affected by dust from the Aral Kum, as the Aral Sea shrinks and is replaced by the newly formed salty desert known as the Aral Kum [43].

Though positive fluctuations have short-term effects, the mid- and long-term effects of climate change on the water resources of the Aral Sea basin are probably more serious [39]. Variations in the seasonality of precipitation may further limit the amount of water available, which could lead to prolonged droughts and water stress [40]. Since 1997, Central Asia's increased temperatures and decreased precipitation have negatively impacted the region's surface moisture content and vegetation. This change suggests that the area will probably get even drier [55]. Future warming is predicted to be greatest in Central Asia, according to recent studies on the region [56].

The findings confirm that drought conditions will result from less rain during the warm months, rising temperatures, and a decrease in total runoff and surface soil moisture [57]. Certain land areas close to the Aral Sea have progressively deteriorated and are classified as having high land degradation [56,58,59]. One significant effect of the high level of land degradation in this area is soil salinization [60,61]. Then, abandoned croplands measuring 920.75 km^2 and 183.10 km^2 were transformed into grasslands and sparse vegetation, respectively.

3. Methodology

Current theories suggest that the increase in life expectancy positively impacts economic growth by enhancing investments in human capital via enhancements in health. A prolonged lifespan enhances the desire to gain information by extending the time period in which the benefits of education may be realized. Further, Ref. [62] observes that investments in skill capital should decrease with age as the remaining period over which benefits can be accrued decreases, while investments in health tend to increase with age. Therefore, the conceptual framework of this research is rooted in the human capital approach [62], which highlights the significance of both health and education as key drivers of human growth [63]. Along these lines, Ref. [64] established the healthcare concept, in which he saw health as a long-term asset that can be enhanced via investment despite its depreciation with age [65]. Therefore, investing in health status encompasses several factors, such as leveraging the benefits of globalization, using electricity, ICT, financial growth, and quality of education. In this study, prior studies primarily provide the empirical basis for variable selection. Proceeding on with the research [66–69], the average life expectancy at birth is now considered an accurate gauge of health conditions. The present study employs a framework proposed by [70–72] for empirical estimates.

$$lex_{it} = f(co_{2it}, health_{it}, gdp_{it}, water_{it}, agr_{it}, urb_{it}, eng_{it}, re_{it}, hc_{it}) \tag{1}$$

In Equation (1), the variable "*lex*" represents life expectancy at birth and serves as an indicator of health status. The variable "co_2" represents carbon dioxide emissions. "*health*" refers to the amount of money spent on the health sector as a proportion of the GDP. "*gdp*" represents the overall economic growth of a country. "*water*" refers to water productivity, while "*agr*" represents the value added in the agriculture sector. "urb" represents the urbanization rate, which is measured by the urban population. "*eng*" refers to the overall energy consumption, while "*re*" represents the proportion of renewable energy consumed in relation to the entire amount of energy utilized. "*hc*" represents the human capital, which is proxied by primary school enrollment percentage (gross).

For the purpose of this research, countries such as Uzbekistan, Tajikistan, Turkmenistan, Afghanistan, Iran, and Kazakhstan have been considered at various points in time between the years 2002 and 2020 (Table 1).

Table 1. Description of variables.

Variables	Description	Year	Source
Lex	Life expectancy at birth (years)	2002–2020	WDI, 2023
CO_2	CO_2 emissions (metric tons per capita)	2002–2020	WDI, 2023
Health	Health expenditure (% of GDP)	2002–2020	WDI, 2023
Gdp	Economic growth proxied by GDP (constant, 2015 USD)	2002–2020	WDI, 2023
Water	Water productivity (hectares per person)	2002–2020	WDI, 2023
Agr	Agricultural value added (% of GDP)	2002–2020	WDI, 2023
Urb	Urbanization rate (%)	2002–2020	WDI, 2023
Eng	Total energy consumption (kWh)	2002–2020	WDI, 2023
Re	Renewable energy consumption (% of total energy consumed)	2002–2020	WDI, 2023
Hc	Human capital proxied by primary school enrollment percentage (gross)	2002–2020	WDI, 2023

Source: Author's own contribution.

By changing Equation (1) to its natural logarithmic format, we may reduce heteroskedasticity among the variables and do direct elasticity-based comparisons. So, the variables under the study have been converted to logarithmic form to get precise results:

$$\begin{aligned} lnlex_{it} = \alpha + \beta_1 lnco_{2it} + \beta_2 lnhealth_{it} + \beta_3 lngdp_{it} + \beta_4 lnwater_{it} + \beta_5 lnagr_{it} \\ +\beta_6 lnurb_{it} + \beta_7 lneng_{it} + \beta_8 lnre_{it} + \beta_9 lnhc_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

in which variables and their long-run elasticities are represented by β_1, β_2, β_4, β_4, β_5, β_6, β_7, β_8, and β_9, respectively; ε denotes the error term; i is the county; t denotes the period. In the present research, panel data spanning the years 2002 to 2020 has been applied for empirical estimation purposes. The World Development Indicators database maintained by the World Bank provides all of the acquired data.

Table 2 demonstrates the statistical characteristics of the variables that are included in the model. The chosen variables (life expectancy, CO_2 emissions, healthcare expenditure, Gross Domestic Product, annual freshwater withdrawal, arable land, urbanization, and energy consumption) are important parameters to show socioeconomic aspects of well-being and livelihood in the Aral Sea basin. The presented data table indicates that the arithmetic mean and median measurements of the complete variable being examined fall within the scope of the highest and lowest recorded values. The mean values of LIFE, CO_2, HEALTH, GDP, WATER, AGR, URB, ENERGY, and RNEW are 4.22, 0.86, 0.43, 24.21, 0.29, 2.68, 3.73, 9.46, and 1.18. Accordingly, a remarkable amount of standard deviation is shown for each of the variables investigated in this research, which are as follows: 0.06, 1.53, 0.63, 1.53, 0.95, 0.62, 0.37, 1.40, and 2.20 for LIFE, CO_2, HEALTH, GDP, WATER, AGR, URB, ENERGY, and RNEW, respectively. There is just a small amount of informational dispersion from each variable's mean value, as measured by their standard deviations.

In order to assess the correlation between variables, the Pearson correlation coefficient has been applied for matrix correlation, which is displayed in Table 3. According to the findings, there exists a positive correlation between the dependent variable (lnlex) and the independent variables $lnco_2$ (0.7341), lnhealth (0.8072), lngdp (0.5274), lnwater (0.5734), lnurb (0.7513), lneng (0.8516), and lnhc(0.2319). Based on these results, it can be inferred that there is a significant and favorable association between the variables. Conversely, an inverse correlation was observed between the dependent variable (lnlex) and the independent variables lnagr (−0.5195) and lnre (−0.4843).

Table 2. Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
Lnlife	133	4.222685	0.0601467	4.033426	4.333296
$lnco_2$	133	0.868574	1.536956	−2.902848	2.730546
lnhealth	133	0.4365907	0.6377832	−2.474791	1.440073
lngdp	133	24.21811	1.530774	21.91039	26.84675
lnwater	133	0.2997316	0.9575457	−1.292567	2.194684
lnagr	133	2.684237	0.6266397	1.455897	3.653975
lnurb	133	3.734349	0.3744607	3.102836	4.329074
lnenergy	133	9.466202	1.400645	5.319253	11.12176
lnrnew	133	1.18776	2.204178	−2.995732	4.167905
Lnhc	111	4.6128	0.0579025	4.330204	4.793394

Source: Computed by Stata 17.0.

Table 3. Correlation Matrix.

	lnlife	lnco2	lnhealth	Lngdp	Lnwater	lnagr	Lnurb	lnenergy	lnrnew	lnhc
lnlife	1.0000									
$lnco_2$	0.7341	1.0000								
lnhealth	0.8072	0.6697	1.0000							
lngdp	0.5274	0.7856	0.2977	1.0000						
lnwater	0.5734	0.8405	0.3971	0.8993	1.0000					
lnagr	−0.5195	−0.7295	−0.3515	−0.6738	−0.8720	1.0000				
lnurb	0.7513	0.9421	0.6357	0.8818	0.8319	−0.6794	1.0000			
lnenergy	0.8516	0.9091	0.7772	0.5711	0.6472	−0.6291	0.8381	1.0000		
lnrnew	−0.4843	−0.8426	−0.3378	−0.8744	−0.7420	0.5137	−0.8755	−0.6506	1.0000	
lnhc	0.2319	0.3294	0.0792	0.5461	0.4927	−0.4688	0.4165	0.1641	−0.4371	1.0000

Source: Computed by Stata 17.0.

4. Empirical Strategies

Comparable to previous literature research investigating the link between life expectancy, CO_2 emissions, and economic development, the empirical estimate involves three primary stages: (i) investigating the cross-sectional dependence features of the underlying data and determining the integration-order of the variables; (ii) investigating the variables of the model that have been established for the long run in the preceding stage; and (iii). In the final stage, a novel approach to checking for Granger non-causality in models based on panel data [68] was implemented in order to investigate the manner in which the relationship between each of the components runs.

4.1. Panel FMOLS and DOLS

Estimating the long-run coefficients is the next most important stage in the empirical estimate technique, which is highlighted in Equations (1) and (2). This phase comes after determining whether the underlying collection of data exhibits co-integration features. Both the F-MOLS technique (completely modified OLS) and the DOLS methodology (dynamic ordinary least square method) were used during our research. It is generally maintained in the empirical literature that the typical OLS (ordinary least square) procedures for the panel may yield misleading outputs, which is why it is viewed as inefficient. Endogeneity and serial correlations are two issues that might arise if OLS algorithms are used. The FMOLS and DOLS methods, both of which are often used in literature as panel estimating methodologies with a focus on heterogeneity, may help address these concerns [73,74].

The FMOLS approach offers a notable benefit in examining the effectiveness of a measure when confronted with mixed-order integrating variables in the co-integrating structure. The aforementioned measures exhibit consistency even when faced with constraints such as sample bias and endogeneity [75,76]. Undoubtedly, the FMOLS methods are suitable for addressing initial levels of residual heterogeneity in the long-term coefficients. Equations (3) and (4), respectively, explain the mathematical forms of these estimators:

$$\beta_{FMOLS} = \left[N^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \left(p_{it} - \underline{p}_i \right)^2 \right]^{-1} \times \left[\sum_{t=1}^{T} \left(p_{it} - \underline{p}_i \right) S_{it} - T\Delta_{\varepsilon u} \right] \quad (3)$$

$$\beta_{DOLS} = \left[N^{-1} \sum_{i=1}^{N} \left\{ \sum_{i=1}^{T} Z_{it} Z'_{it} \right\}^{-1} \times \left\{ \sum_{t=1}^{T} Z_{it} S_{it} \right\} \right] \quad (4)$$

Here, p is the explanatory variable; S denotes the dependent variable; Z is the vector on regressors where $Z = p - \overline{p}$.

The DOLS and FMOLS estimation methods are preferable to within-group-based estimation, as they account for between-group-based estimation [73]. The measures under consideration incorporate endogeneity concerns by accounting for temporal precedence and permitting the use of heteroskedastic standard errors. Accordingly, the DOLS approach is superior to the FMOLS methods due to its computational simplicity and ability to minimize biases [77]. The utilization of leads and lags in the Differenced-Ordinary Least Squares (DOLS) approach is advantageous in addressing the issues pertaining to the order of integration and the presence or absence of co-integration.

4.2. Panel Causality Estimation Method

As part of our methodology, we additionally utilize The Juodis, Karavias, and Sarafidis Granger non-causality test, which is based on the Granger causality framework [78]. The approach is applicable in scenarios where the coefficients are either homogeneous or heterogeneous. The technology under consideration exhibits enhanced power and size performance in comparison to the current tests [79]. The method employed is the widely recognized Half-Panel Jackknife (HPJ) technique. To provide a comprehensive depiction, we present a condensed representation of the procedure as depicted below:

$$y_{i,t} = \varphi_{0,i} + \sum_{n=1}^{N} \varphi_{n,i} y_{i,t-n} + \sum_{n=1}^{N} \beta_{n,i} x_{i,t-n} + \varepsilon_{i,t} \quad (5)$$

For $i = 1, \ldots, N \& t = 1, \ldots, T$. $\varphi_{0,i}$ are individual-specific effects, $x_{i,t}$ is considered to be a scalar, $\varepsilon_{i,t}$ are errors, $\varphi_{n,i}$ are the heterogeneous autoregressive coefficients, and $\beta_{n,i}$ are the heterogeneous feedback coefficients or Granger causality parameters to be estimated for all variables. The average Wald statistic is deployed as follows to test for the non-causality null hypothesis.

$$Avarage\ Wald\ statistics \rightarrow \underline{W}_{N,T} = \frac{1}{N} \sum_{i=1}^{N} W_{i,t} \quad (6)$$

$W_{i,t}$ demonstrates the individual Wald statistics for the i-th country, which is allied to the individual test $H_0 : \beta_{n,i} = 0$ for all i and p (selected covariates do not Granger-cause the dependent variable) and $H_1 : \beta_{n,i} \neq 0$ for some i and p (H0 is violated) [78,79].

5. Results and Discussion

The outcomes of the panel unit root test are presented in Table 4. The results obtained demonstrate that it became evident that all variables investigated demonstrated proof of stationarity upon being evaluated using first-order differencing. As a result, the null hypothesis of the presence of a unit root was eliminated, leading to the conclusion that there is evidence of an order integration phenomenon among the variables.

Table 4. Unit root test findings.

	Fisher-Type Tests		IPS Test	
	Fisher-PP Statistics		**IPS**	
	I(0)	I(1)	I(0)	I(1)
lnlife	24.6808 **	45.0363 ***	3.1227	−2.4854 ***
$lnco_2$	36.8649 ***	77.1292 ***	0.0908	−5.1074 ***
lnhealth	54.2651 ***	135.7264 ***	−2.4653 **	−4.6342 ***
lngdp	82.8381 ***	45.1666 ***	1.9847	−3.9963 ***
lnwater	48.7691 ***	69.8739 ***	0.9574	−5.4605 ***
lnagr	21.8014 **	125.2353 ***	−1.0044	−5.8897 ***
lnurb	80.1958 ***	25.3746 ***	5.4800	−2.4212 ***
lnenergy	20.2609	153.6388 ***	−1.4537 *	−5.3652 ***
lnrnew	24.9334 **	186.3092 ***	−2.1906 ***	−6.0414 ***
lnhc	53.9988 ***	111.3681 ***	1.2568	−3.1174 ***

Note: Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. For the Im-Pesaran-Shin (IPS) test, T-bar test statistics values are shown. For the Fisher-type test, inverse chi-squared test statistics are presented.

5.1. CO_2—Life Expectancy

Based on the findings presented in Table 5, the results obtained from the OLS, FMOLS, DOLS, and CCR estimation approaches demonstrate that CO_2 emissions have a substantial and adverse effect on the life expectancy of all the countries examined. Precisely, a 1% increase in the amount of CO_2 emissions in the selected region results in a 0.050%, 0.046%, 0.048%, and 0.047% reduction in life expectancy. In the case of the eight countries of the Aral Sea basin, a rise in carbon emissions in line with climatic changes decreases life longevity. Moreover, the results have been verified by the outputs of the Driscoll–Kraay estimator. Additionally, the findings of our empirical estimations are in line with the studies [68,80–82].

Table 5. Regression results.

	(1)	(2)	(3)	(4)	(5)
Variables	**OLS**	**FMOLS**	**DOLS**	**CCR**	**Driscoll–Kraay**
$lnco_2$	−0.0509 ***	−0.0465 ***	−0.0483	−0.0471 ***	−0.0509 ***
	(0.0101)	(0.00915)	(0.0315)	(0.0105)	(0.00747)
lnhealth	0.0321 ***	0.0534 ***	0.0772 ***	0.0532 ***	0.0321 ***
	(0.00969)	(0.00898)	(0.0241)	(0.00794)	(0.00505)
lngdp	0.00188	0.0141 *	0.0332	0.0138	0.00188
	(0.00787)	(0.00830)	(0.0247)	(0.00880)	(0.0110)
lnwater	0.0344 ***	0.0250 **	0.00356	0.0254 *	0.0344 **
	(0.0103)	(0.0120)	(0.0314)	(0.0132)	(0.0155)
lnagr	0.0208 **	0.0179 **	−0.00468	0.0177 *	0.0208 ***
	(0.00892)	(0.00888)	(0.0202)	(0.00999)	(0.00690)
lnurb	0.0666 *	−0.0306	−0.0515	−0.0284	0.0666 *
	(0.0392)	(0.0392)	(0.105)	(0.0322)	(0.0361)
lnenergy	0.0524 ***	0.0576 ***	0.0441 ***	0.0575 ***	0.0524 ***
	(0.00618)	(0.00486)	(0.0158)	(0.00514)	(0.00607)
lnrnew	0.00298	0.000570	0.00273	0.000355	0.00298
	(0.00470)	(0.00445)	(0.0220)	(0.00549)	(0.00338)
lnhc	0.103 *	0.233 ***	0.0716	0.226 ***	0.103 *
	(0.0557)	(0.0575)	(0.149)	(0.0457)	(0.0593)
Constant	2.910 ***	2.331 ***	2.871 ***	2.363 ***	2.910 ***
	(0.285)	(0.287)	(0.617)	(0.239)	(0.272)
Observations	111	110	108	110	111
R-squared	0.870	0.664	0.931	0.769	0.870
id	7	7	7	7	7

Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.2. Health Expenditure—Life Expectancy

The outcomes indicate that government initiatives related to healthcare spending have a substantial and beneficial effect on the average lifespan in chosen economies. The outcomes derived from the OLS, FMOLS, DOLS, and CCR estimation methods highlight that health expenditure has a significant and advantageous impact on the life expectancy of each country analyzed. More specifically, life expectancy increases by 0.0532%, 0.0534%, 0.0772%, and 0.0531%, respectively, for every 1% increase in health expenditures in the selected region. Even more health expenditure is needed to cover the health losses that originated since the drying of the Aral Sea in the 1970s. In addition, the outcomes of the Driscoll–Kraay estimator, which had a coefficient of 0.0321%, have established that the results are accurate. These findings have been validated through the works of [83–85].

5.3. GDP (Gross Domestic Product)—Life Expectancy

Based on the results, the coefficient for GDP per capita is 0.014, indicating a positive and statistically significant relationship at the 10% significance level. This means that a 1% rise in per capita GDP results in a 0.014% rise in lifespan. This finding suggests that economic expansion facilitates authorities in augmenting spending on healthcare, ensuring financial stability, and enabling individuals to pay sufficient medical interventions to tackle diverse ailments, hence enhancing life expectancy. Especially in hazardous ecological conditions in the Aral Sea basin, medicine needs more financial and technological support. This outcome aligns with the findings of [86–88].

5.4. Water—Life Expectancy

The coefficients of water productivity of 0.0344%, 0.0250%, and 0.0254%, correspondingly, as determined using OLS, FMOLS, and CCR estimation methods, are favorable and statistically significant. The situation of water being distributed by upstream countries puts life expectancy at risk for downstream economies. The findings have been corroborated by the research conducted, which indicates that the implementation of enhanced sanitation and clean water for consumption infrastructure has led to notable advancements in public health within Aral Sea basin countries [89,90].

5.5. Agriculture—Life Expectancy

Next, the long-term estimations from Table 5 showed that agricultural production had a positive and statistically significant effect on life expectancy in the selected countries. The outcomes from the OLS, FMOLS, CCR, and Driscoll–Kraay estimations indicate that a one-percent rise in agriculture is associated with a 0.0208%, 0.0179%, 0.0177%, and 0.0208% increase in life expectancy, respectively. However, the provision of water for agriculture is another alarming issue that might cause conflict between countries of the basin. The findings have been confirmed by the research conducted [91,92].

5.6. Urbanization—Life Expectancy

Furthermore, the urbanization indicator, demonstrated by the OLS and Driscoll–Kraay estimator, is 0.066, which is favorable and statistically substantial at the 1% level. This means that for every 1% rise in urbanization, life expectancy rises by 0.066%. Indeed, urbanization offers access to amenities, such as advanced healthcare services that effectively promote wellness and enhance human longevity. This outcome is pertinent to the findings [93–95].

5.7. Energy Consumption—Life Expectancy

The energy consumption coefficients obtained through OLS, FMOLS, DOLS, CCR, and Driscoll–Kraay estimations are 0.0524%, 0.0576%, 0.0441%, 0.0575%, and 0.0524%, respectively. These values are favorable and statistically substantial at the 1% level, indicating that a 1% increase in energy consumption outcomes in a corresponding rise in lifespan of 0.0524%, 0.0576%, 0.0441%, 0.0575%, and 0.0524%. And the outcomes are in line with [96]. On the contrary, the study found that renewable energy has no substantial effect on life expectancy in the chosen economies. This can be related to the fact that the majority of the basin countries have fossil fuel-based infrastructure. This can be mostly attributed to the rising usage of non-renewable energy sources, particularly oil, as well as additional fuels, which is driven by population expansion and the poor utilization of regional energy resources [97–99].

5.8. Human Capital—Life Expectancy

Lastly, the coefficients derived using OLS, FMOLS, CCR, and Driscoll–Kraay estimates for education, which is considered a measure of human capital, are 0.103%, 0.233%, 0.226%, and 0.103%, respectively. The data shows that these outcomes are both positive and statistically substantial at the 1% level. This means that a 1% gain in schooling results corresponds to an increase in longevity of 0.103%, 0.233%, 0.226%, and 0.103%. Furthermore, access to education fosters information acquisition, promoting vigilance and attentiveness toward health preservation, ultimately leading to an extended lifespan. This outcome aligns with the insights drawn by Ref. [100].

6. Conclusions

The majority of the existing studies recommend that all Aral Sea basin countries should minimize water pressure, mostly resulting from the agriculture sector. Considering climatic changes and negative environmental changes happening in the deserts of the dried Aral Sea, more green growth strategies should be supported, both financially and technically. The increasing population of the Aral Sea basin can be directed to less water-dependent industries such as tourism, IT, and other soft industries that can generate even more revenue compared with agriculture.

The present research has examined the impact of CO_2 emissions, health spending, GDP, water usage, agricultural output, urbanization, renewable and non-renewable energy consumption, and the role of schooling on life expectancy at birth in the Aral Sea region. These outcomes might be related to outdated public infrastructure inherited from the Soviet period and environmental degradation in the Aral Sea basin. This research utilized data from the years 2002 to 2020 and employed various econometric approaches, including FMOLS, DOLS, and Driscoll–Kraay. The outcomes of the study reveal that health spending, GDP, water, agriculture output, energy consumption, and education rate have a positive impact on life expectancy, but CO_2 emissions have a negative impact on life expectancy. The most important policy takeaway from this study is the need to develop and implement comprehensive policies that take into account health spending, GDP, water, agricultural output, energy consumption, and education level in order to ensure health status. Furthermore, we advocate several policies in accordance with the results of the research:

Optimize the water management strategy and facilities: Formulate an integrated water management plan to enhance the region's environmental position while ensuring an appropriate usage of its water resources. Furthermore, the authorities of the region ought to undertake a comprehensive and progressive rebuilding of water management facilities, together with broad adoption of water-saving technology and decreasing sewage, to accelerate progress.

Enhance Healthcare Investment: Authorities have to give precedence to the allocation of supplementary government resources in order to enhance the health system and broaden the availability of medical treatment to all individuals. Authorities have the ability to allocate a greater portion of the national budget to the healthcare industry. Another way to improve healthcare funding is through the establishment or expansion of health insurance schemes, which pool resources like premiums and government payments.

Addressing and reducing CO_2 emissions: Elevated levels of CO_2 emissions have a detrimental impact on life expectancy. CO_2 emissions have the potential to cause air pollution and poison the ecosystem. Individuals may have a range of illnesses pertaining to the cardiovascular and respiratory systems, which might reduce their lifespan, necessitating efforts to mitigate carbon dioxide emissions. Governments endeavor to incorporate ecologically sustainable practices across all sectors to enhance the overall well-being of individuals.

Accelerated economic growth: Increased economic growth positively impacts life expectancy. The presence of economic growth enables the establishment of advanced medical facilities such as state-of-the-art hospitals, complex medical equipment, and the development of effective drugs inside a country. Hence, implementing an effective strategy for promoting economic growth is crucial in order to enhance the life expectancy of individuals.

Strategic urban development: Urban development increases life expectancy. Structured urbanization provides individuals with health-related advantages such as minimal pollution, a lush landscape, fresh water, suitable sanitation facilities, sufficient medical facilities, and efficient medical services. Hence, it is imperative to implement urbanization policies that are both dynamic and health-oriented to guarantee a longer lifespan for individuals.

Enhancing Education: Education has a positive impact on lifespan by promoting greater health consciousness and facilitating the maintenance of a healthy lifestyle. Acquiring knowledge and receiving a comprehensive education empower individuals to comprehend the norms and regulations pertaining to health. Therefore, it is imperative to guarantee high-quality education for everyone to protect long-term sustainability.

Similar to any other study, the present investigation is not exempt from shortcomings. Due to insufficient data, we were unable to incorporate additional factors that influence well-being, such as calorie consumption, healthcare accessibility, lifestyle choices, criminal activity, and bribery levels. It is advised that future study efforts include elements that include greater panel regions.

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