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MIGRATION RATHER THAN UNEMPLOYMENT? REGIONAL LABOR ADJUSTMENT UNDER LONG-TERM ENVIRONMENTAL STRESS

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ABSTRACT. Long-term environmental degradation may reshape regional labor markets through outward mobility without a corresponding rise in recorded unemployment. This study examines labor-market adjustment in environmentally exposed regions of the Aral Sea basin. We use administrative labor-register data for Uzbekistan's 14 regions during 2007–2025, excluding 2017, yielding 252 region-year observations. The analysis combines fixed-effects models, event studies, a basin-wide desiccation index, wild-cluster bootstrap inference, and regional-pair randomization tests. Kazakhstan provides a descriptive comparison. High-exposure regions have an estimated external-migration share 3.35 percentage points above low-exposure regions, with limited bootstrap support ($p = 0.076$). The estimated post-2017 increase in this differential is 3.34 percentage points ($p = 0.101$). Differences in unemployment, informal employment, and inactivity are not robust under bootstrap inference. Only two regions have high exposure, and pretrend tests reject parallel trends, limiting causal interpretation. The findings are consistent with migration as a potential adaptation margin but do not establish that migration prevents unemployment or that environmental degradation causes the observed differences. Regional adaptation policy should monitor labor mobility alongside unemployment and strengthen local employment alternatives and migrant protection.

JEL Classification: J61, R23, Q56

Keywords: environmental degradation, labor migration, migration as adaptation, regional labor markets, Aral Sea, Uzbekistan

Introduction

Long-term environmental degradation poses a labor-market challenge that extends beyond the locations where ecological damage originates. Declining water availability, soil degradation, heat exposure, and lost agricultural productivity can reduce local employment opportunities, but they do not necessarily translate into higher unemployment. Workers may instead change sectors, leave affected regions, or enter established migration networks. Understanding which adjustment margin dominates is important for climate adaptation policy because regions that appear stable in conventional employment statistics may in fact be experiencing substantial labor and population outflows.

The Aral Sea began drying up in the 1960s, when Soviet planners diverted the Amu Darya and Syr Darya rivers to irrigate cotton and rice fields. By the late 2010s, the Aral Sea had lost almost 90 percent of its 1960 surface area, turning the exposed seabed into a major source of salt and dust storms that affected territories far beyond the former shoreline (Ahn et al., 2024; Yang et al., 2020). For residents of Karakalpakstan and Khorezm, this disaster was not just an abstract environmental loss, but a harsh reality that completely changed the region's way of life, agricultural potential, irrigation opportunities, and traditional sources of income. Uzbekistan's leadership is taking measures to reduce the consequences of the Aral Sea region's global ecological crisis, including replanting trees, maintaining ecological stability, improving the population's socio-economic situation, and diversifying income sources (President of the Republic of Uzbekistan, 2023).

Research on the crisis has concentrated on hydrology, dust transport, and public health (Ahn et al., 2024; Banks et al., 2022; Wang et al., 2022; Ziganshina & de Schutter, 2022). Far less is known about how the crisis reached the surrounding regions' labor markets. Research on environmental change and rural livelihoods suggests an effect is likely, since declining water availability and land degradation reduce agricultural productivity, shift labor allocation, and push affected workers to seek employment elsewhere (Colmer, 2021; Fishman & Li, 2022; Huang et al., 2020). In Central Asia, this push meets a ready channel. Labor migration to Kazakhstan has been part of everyday life in Uzbekistan since the 1990s, and remittances support a large share of rural households. Recent cross-country evidence from post-transition economies further indicates that remittance inflows can influence employment incentives in migrant-sending countries, showing that labor mobility affects origin regions not only through worker outflows but also through household labor-supply decisions (Peković, 2025). The employment and GDP consequences of large-scale labour outflows have also been analysed econometrically for Ukraine's forced migration in 2022 to 2025 (Y. Vovk et al., 2026). Time-series evidence for the Gambia likewise links migration and remittances to employment in agriculture (Ceesay, 2020). Whether the Aral crisis feeds this flow, and how strongly, remains an open question. The regional dimension is important because the Aral crisis does not affect all territories equally. The former shoreline, the Amu Darya delta, water scarcity and salt dust exposure place Karakalpakstan and Khorezm closer to the environmental source of risk than other Uzbek regions. This geography allows labor mobility to be read not only as an economic outcome but also as a social response to long-term ecological degradation. For this reason, the article treats migration as one channel through which exposed regions adapt when local

agriculture and nonagricultural employment cannot absorb the pressure created by environmental change.

Thus, this mechanism is not limited to a direct and linear transition from environmental degradation to migration. In the Aral Sea basin, the reservoir's shrinkage primarily transforms the local production environment. Reduced water availability, soil salinization, and salt and dust storms undermine agricultural stability and weaken rural incomes. When adjacent non-agricultural sectors cannot absorb the released labor force, migration becomes the most practical, and arguably the only, way for households to protect their income and diversify risks across territories. This chain links ecosystem degradation to regional labor mobility, allowing migration to be viewed as an adaptive response within a socio-ecological system under profound stress.

The goal of this study is to determine which labor-market adjustment margin dominates in regions exposed to long-term environmental degradation. Accordingly, the following research question is addressed:

RQ1. Which adjustment margin–outward migration, unemployment, inactivity, or informal employment is most strongly associated with environmental exposure? Distinguishing among these channels is important because each represents a different form of regional vulnerability and requires a different policy response.

The study's contribution extends beyond documenting labor mobility within a single environmental crisis zone. It develops a transferable regional adaptation framework in which the labor-market consequences of environmental degradation depend on local absorptive capacity. Where non-agricultural sectors can absorb displaced workers, environmental stress may produce sectoral reallocation within the region. Where that capacity is weak, but migration networks are established, adjustment is more likely to occur through outward mobility. This framework is relevant to other agriculture-dependent regions affected by water scarcity, land degradation, drought, and long-term ecosystem decline.

The research question is examined using the Labor Resources Balance, an administrative register covering all 14 regions of Uzbekistan from 2007 to 2025 and disaggregating employment into formal, informal, and foreign components. Climate-migration research on transition countries rarely observes workers abroad directly and usually relies on household surveys (Hoffmann et al., 2020; Letta et al., 2024). The register fills that gap. Regions are classified by geographic exposure to the desiccation zone, estimate fixed-effects and event-study models, and link the results to an annual index of the sea's shrinkage. We then set the Uzbek evidence against Kyzylorda, the Kazakh region north of the former sea, to see whether the pattern holds across the basin.

The estimates indicate that exposed regions adjust mainly through higher outward labor mobility. External migration in Karakalpakstan and Khorezm is about 3.3 percentage points higher than in less-exposed regions, and the gap widens after 2017. No robust unemployment differential is detected; labor outflows may relieve pressure on local markets, but this mechanism is not directly established. Kyzylorda shows the same profile of low income, agricultural dependence, and steady outflow, although Kazakhstan channels its migrants to domestic growth centers rather than abroad. The two states also chose different responses to the sea itself. Kazakhstan restored part of the northern basin behind the Kokaral Dam (Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, 2026), while Uzbekistan lost its southern sea and turned to greening the exposed seabed. We interpret the Aral Sea crisis as a process of long-term labor redistribution and formulate the resulting implications for public policy.

1. Literature review

This study draws on three strands of research to identify the gaps that a regional administrative register can address. The first concerns how environmental change and shocks reach rural livelihoods and the regional labor market. Recent empirical evidence shows that environmental stress reduces agricultural productivity and shifts labor allocation across economic activities. Higher temperatures can shift labor from farming to non-farm work, while drought affects agricultural production, work patterns, and households' capacity to diversify their livelihoods (Afridi et al., 2022; Colmer, 2021; Fishman & Li, 2022; Huang et al., 2020). Compound drought events may also interact with structural vulnerability, shaping both the incentive and the ability to migrate (Thalheimer et al., 2022). These findings suggest that declining agricultural productivity initiates a broader process of labor reallocation rather than producing a uniform increase in local unemployment. Agriculture also remains a primary source of employment in much of sub-Saharan Africa, where drought is prominent, although sustainable agricultural strategies are hard to implement at the grassroots (Cheteni & Umejesi, 2022). This study focuses on how and where declines in agricultural productivity trigger labor reallocation. Evidence from Uzbekistan also points to predominantly service-led labor reallocation, with manufacturing playing a limited role in net job creation (Tagaev et al., 2026).

The conceptual foundation of this study is the interpretation of migration as a potential adaptation to environmental and climatic stress developed in the seminal contributions of McLeman and Smit (2006) and Black et al. (2011). More recent evidence indicates that migration responses to environmental stress vary according to agricultural dependence, household income, existing mobility networks, exposure to water-related hazards, the availability of local livelihood alternatives (Caretta et al., 2023; Helbling & Meierrieks, 2021; Hoffmann et al., 2020; Zatonatskiy et al., 2024). This is aligned with the research on push-pull factors of migration (Karolyi et al., 2025; Kochaniak et al., 2024; Tutar et al., 2025) as well as gravity theory in migration behavior studies (Martyniuk et al., 2025). In agriculture-dependent settings, drought-induced income losses can increase migration, whereas irrigation and access to non-farm employment can weaken this relationship (Fishman & Li, 2022). Evidence from rural Gambia similarly suggests that adaptive capacity matters more for household vulnerability than biophysical exposure itself (Ceesay et al., 2026). Environmental stress may therefore encourage outward mobility, but structural vulnerability can also restrict the resources required to migrate (Thalheimer et al., 2022). The relationship is therefore conditional rather than uniform. Cross-country evidence indicates that unemployment, poverty, employment opportunities, wage differentials, and household resources can mediate or outweigh environmental drivers of migration (Cattaneo et al., 2019; Helbling & Meierrieks, 2021; Hoffmann et al., 2020; Khalid & Urbański, 2021; Mishchuk & Oliinyk, 2025). A long-standing weakness is the reliance on household surveys as primary data (Letta et al., 2024), which this study addresses by examining regional differences in the number of people working abroad. Recent bibliometric evidence further indicates that research linking migration to sustainable development remains fragmented, with a continuing need for systematic and interdisciplinary analysis of the economic, social, and environmental dimensions of mobility (Lyeonov et al., 2025).

A third line of research documents the Aral Sea's long-term desiccation, environmental consequences, and partial recovery (Ahn et al., 2024; Banks et al., 2022; Yang et al., 2020). Recent studies have traced the life cycle of dust from the exposed seabed (Banks et al., 2022) and provided a geographical assessment of the crisis's scale (Ahn et al., 2024). Water scarcity has also been studied in the lower reaches of the Amu Darya (Wang et al., 2022) and in the context of the transboundary management of the rivers that feed the sea (Ziganshina & de

Schutter, 2022). In a broader sense, there is very little research in English on climate change and sustainable development in Central Asia, and the existing literature is mostly focused on public policy, land use, and water resource management in general, rather than on regional development characteristics and labor market adaptation (Marcombe & Tagaev, 2025).

In the context of global warming, inland sea basins are now highly sensitive to climate change, and irrigated agricultural land needs to adapt rapidly to changing conditions (Barrett et al., 2017; Kalashnikova et al., 2023). However, the scientific community has largely ignored how environmental pressures are changing rural life in Uzbekistan and affecting the population's lifestyles and mobility (Otrachshenko, Iliyas, et al., 2024; Otrachshenko, Popova, et al., 2024).

Otrachshenko, Popova, et al. (2024) and Galdini (2024) show how climate factors can exacerbate income inequality, drive structural shifts, and create labor surpluses. The lack of research linking the Aral Sea basin's ecology to the local labor market was the primary impetus for this study.

Despite the severe environmental stress experienced in the Aral Sea basin, previous research has not examined regional labor-market adjustment using administrative data that distinguish external migration, unemployment, inactivity, and informal employment. The theoretical framework suggests that environmental degradation weakens agricultural livelihoods and pushes labor out of traditional economic activities. Where local non-agricultural sectors have limited absorptive capacity and migration networks are established, this pressure is expected to be reflected primarily in outward labor mobility. Based on this mechanism, the following hypotheses are proposed:

H1. Greater exposure to long-term environmental degradation is expected to be positively associated with the share of external migration.

H2. The external-migration differential between high- and low-exposure regions is expected to exceed the corresponding differentials in unemployment, inactivity, and informal employment.

The cross-country comparison addresses an additional research question:

RQ2. Does the Aral-exposed region of Kazakhstan exhibit a directionally similar outward-mobility pattern despite differences in migration destinations and statistical measurement?

2. Data and methods

In 1960, the Aral Sea covered about sixty-eight thousand square kilometers and supported a productive inland fishery. From the 1960s onward, irrigated agriculture spread across the Amu Darya and Syr Darya basins, diverting water from these basins to the sea. Reconstructions from 1960 to 2018 show that the area shrank by nearly 88 percent (Yang et al., 2020). The Aral Sea has become a desert of sand and salt, with fertilizer and pesticide residues carried into the air during salt storms and transported for thousands of kilometers (Banks et al., 2022). The water crisis is directly linked to the rural economy, with agriculture in the irrigated areas downstream of the two rivers employing a large portion of the rural workforce (Wang et al., 2022).

This environmental impact is unevenly distributed across Uzbekistan, with Karakalpakstan and Khorezm suffering the most from dust, salinity, and water shortages. Bukhara and Navoi are also vulnerable because they lie in the upper Amu Darya Basin. Although other regions are far from the immediate disaster zone, dust and salt storms occur occasionally. The worst-affected region in Kazakhstan is Kyzylorda, near the Northern Aral

Sea (Ahn et al., 2024). This geography allows us to rank regions by vulnerability using criteria independent of labor market outcomes.

The core data come from Uzbekistan's Labor Resources Balance, an administrative register maintained for each of the 14 regions each year from 2007 to 2025. Each region-year reports the economically active population, total employment, and breakdown of employment into formal, informal, and foreign components. It also provides the number of people seeking work, those not in the labor force, the total labor force, and the average population. The register is internally consistent, since formal, informal, and foreign employment sum to total employment in every year we use.

Two points warrant attention regarding this data. In 2018, the statistical office revised its labor methodology, changing how it classified informal employment and external labor migration. We treat this as a national-level discontinuity and account for the fixed effects. The identification was based on intra-year differences across regions, and 2017 was excluded as a transitional year.

Excluding 2017 leaves a balanced panel of 14 regions over 18 included years (2007–2016 and 2018–2025), yielding 252 region-year observations (14 × 18). We build five outcomes from the register. External migration share is the number of people working abroad as a share of the economically active population, directly measuring the migration channel. Informal and formal shares divide these components by total employment. The unemployment rate is the gap between the economically active population and total employment, expressed as a share of the economically active population, and is applied uniformly across years. Economic inactivity is the share of total labor resources outside the labor force. Summary statistics are presented in Table 1.

Table 1. Summary statistics, Uzbekistan region-year panel, 2007 to 2025, excluding 2017

Variable	Mean	Std. dev.	Min	Max
External migration, % of active	7.59	5.51	0.59	21.82
Unemployment rate, %	6.38	2.11	3.26	11.06
Informal employment, % of employed	35.22	9.22	3.57	57.63
Formal employment, % of employed	56.57	12.86	30.02	89.79

Notes. 252 region-year observations across 14 regions and 18 included years (2007–2016 and 2018–2025); 2017 is excluded as a transitional year. Source: Labor Resources Balance of Uzbekistan.

We ranked exposure into three geographic tiers. The high tier includes Karakalpakstan and Khorezm, delta regions closest to the former shoreline. The medium tier includes Bukhara and Navoi, and the low tier includes the remaining ten regions. Because the ranking is fixed and geographic, region-fixed effects absorb its level, and identification comes from the interaction of exposure with time.

Table 2. Environmental exposure classification of Uzbek regions

Exposure group	Regions	Environmental basis
High exposure	Karakalpakstan and Khorezm	Closest location to the former Aral Sea zone and lower Amu Darya delta
Medium exposure	Bukhara and Navoi	Wider Amu Darya basin exposure and water stress
Low exposure	Other ten regions	Greater distance from the desiccation zone

Notes. The classification is based on geographic exposure to the Aral Sea desiccation zone and the lower Amu Darya system. It is fixed over time and is used to compare adjustment patterns across regions. We

retain three tiers to distinguish direct delta exposure from wider basin exposure. Combining the high and medium tiers would impose a common exposure-group coefficient despite their different geography and economic structures. The two-region size of each tier limits inference and is addressed through the bootstrap and, for the high tier, pairwise randomization checks reported below.

To connect the labor market analysis more directly to environmental change, we use two measures of exposure. The first is a fixed geographic exposure measure based on proximity to the former Aral Sea zone and location within the lower Amu Darya system. Karakalpakstan and Khorezm are considered regions with high environmental pressure in this study, as they are located closest to the former coastline and directly face water shortages, soil salinization, and the risk of dust storms. The Bukhara and Navoi regions are classified as having a moderate impact because they are geographically connected to the Amu Darya basin but are far from the main source of the environmental crisis. The remaining regions are classified as the low-exposure group. The second measure is a basin-wide desiccation index. Using the 1960 area of the Aral Sea as the baseline, the index records the share of the original sea area lost each year. It is based on published reconstructions of the Aral Sea's surface area and subsequent estimates, with linear interpolation between observed points. We use this index as a time-varying environmental pressure indicator and interact it with regional exposure. Since the index is measured at the basin level rather than separately for each region, we interpret it as supporting evidence rather than as a stand-alone causal measure.

To situate the regional results within the broader structural picture, Uzbek employment data by economic activity for 2010–2025 are used. For Kazakhstan, gross regional product, rural population, and migration indicators are drawn from official regional statistics (Bureau of National Statistics of Kazakhstan, 2024, 2026). Kazakhstan measures regional mobility primarily by net migration rather than by the number of workers abroad, so the indicators are not directly comparable. The main panel analysis rests on the Uzbek data, while the Kazakh evidence supports the structural comparison reported in Table 6.

Four specifications are estimated. The first estimates the average exposure differential by regressing each outcome on year fixed effects and indicators for high and medium environmental exposure, with the logarithm of total employment included as a scale control. The coefficients represent average differences from the low-exposure group after accounting for national shocks. The second specification adds region fixed effects and interacts the exposure tiers with a post-2017 indicator to estimate differential changes over time.

The third specification is an event-study model that interacts the high-exposure indicator with a full set of year indicators, using 2016 as the reference year. This specification traces the evolution of the external-migration differential before and after the beginning of the post-period. The fourth specification interacts regional exposure with the basin-wide desiccation index to estimate whether the regional differential changes with the intensity of Aral Sea area loss. Recent guidance on multi-period designs informs the specification of dynamic effects (Callaway & Sant'Anna, 2021), while synthetic-control estimates provide an additional comparative robustness check (Abadie, 2021).

The empirical strategy follows recent guidance on multi-period and event-study designs (Callaway & Sant'Anna, 2021; Roth et al., 2023). Because the high-exposure group contains only two regions, conventional cluster-robust inference may overstate precision. Cluster-robust estimates are therefore supplemented with wild-cluster bootstrap p-values using Rademacher weights and a randomization test over all 91 possible regional pairs (MacKinnon et al., 2023; MacKinnon & Webb, 2017). The fixed-effects estimates are interpreted in light of potential treatment-effect heterogeneity (de Chaisemartin & D'Haultfoeuille, 2020), while synthetic-control estimates provide an additional robustness check (Abadie, 2021). Because the post-period begins in 2018, when the national labor-statistics methodology changed, the estimates

are interpreted as differential divergence after 2017 rather than as the pure causal effect of a discrete environmental shock.

3. Results

The external migration share by exposure group over the full study period is shown in Figure 1. The high-exposure regions sit above the rest for almost the whole sample.

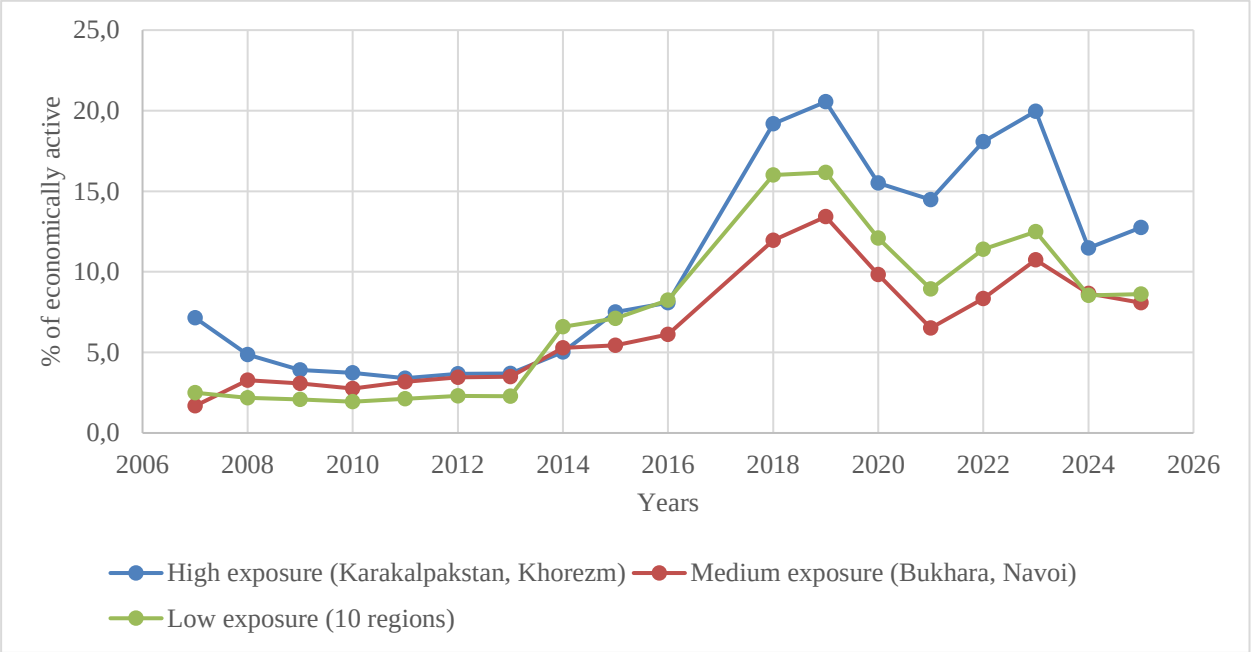


Figure 1. External labor migrants, % of economically active population

Notes. External labor migrants as a share of the economically active population, by Aral exposure group. The vertical line marks 2018, the year of the national labor revision, and the start of the post-period. Source: Authors' calculations based on the Labor Resources Balance.

The three groups move together until mid-decade, after which the high-exposure line pulls away, reaching nearly a fifth of the economically active population in 2018 to 2023, while the low group stays near eight to sixteen percent, and the medium group lower still. The medium tier does not follow the high tier, an early sign that distance to the shoreline is not the whole story, a point we return to below. The average exposure differential is reported in Table 3. The high-exposure regions have an external-migration differential of 3.35 percentage points in the economically active population relative to the low tier.

Table 3. The magnitude of the gap compared to the control group

Outcome	Tier	Coef. (pp)	p cluster	p bootstrap
External migration	High	+3.35	0.000	0.076
	Medium	-0.19	0.888	0.900
Unemployment rate	High	+0.52	0.070	0.133
	Medium	-0.18	0.228	0.305
Informal share	High	-1.92	0.241	0.284
	Medium	-6.51	0.006	0.126
Inactivity	High	+2.00	0.516	0.630
	Medium	-7.53	0.003	0.147

Notes. Each block corresponds to a separate regression estimation with year fixed effects and controls for the logarithm of employment. The coefficients were expressed as percentage points relative to the baseline group. Robust standard errors are clustered at the regional level. The "Bootstrap" column shows p-values obtained using the wild-cluster bootstrap with the null hypothesis fixed. N = 252.

The coefficient on high environmental risk exposure for outward migration is positive, at 3.35 percentage points, compared with a panel average of about 7.5%. This estimate is robustly supported by the cluster-robust standard errors test, while the wild-cluster bootstrap test yields weaker, but still marginal, support at the 10% significance level. The bootstrap p-value of 0.076 indicates significance at the 10% level but not at 5%; therefore, the migration gap is interpreted as suggestive evidence of a regional pattern rather than a precisely estimated causal effect.

The unemployment gap is small, at 0.52 percentage points, and the wild-cluster bootstrap test does not support this estimate. Estimates for informal employment and economic inactivity are also unstable. The negative coefficients for the moderate impact group appear to reflect Navoi region's specific industrial structure, where mining and the formal employment sector play a key role, rather than the overall impact of the Aral Sea crisis.

Table 4 includes region-fixed effects and interacts with each tier using the post-2017 indicator. After 2017, the estimated external-migration differential for the high tier increases by 3.34 percentage points relative to controls, with a wild bootstrap p-value of 0.101, slightly above the 10% significance threshold.

Table 4. Post-period divergence, exposure tier interacted with the post-2017 indicator

Outcome	Interaction	Coef. (pp)	p cluster	p bootstrap
External migration	High x Post	+3.34	0.000	0.101
	Medium x Post	-2.13	0.046	0.140
Unemployment rate	High x Post	-0.76	0.072	0.116
	Medium x Post	-0.50	0.108	0.190
Informal share	High x Post	-0.30	0.926	0.931
	Medium x Post	-6.52	0.109	0.198
Inactivity	High x Post	-2.35	0.287	0.375
	Medium x Post	+5.49	0.002	0.149

Notes. Each block was estimated using a two-way fixed-effects regression with region- and year-fixed effects. Post-indicator switches in 2018. Inference follows the same procedure as in Table 3. N equals 252.

The unemployment interaction for the high-tier is negative, so the small unemployment gap narrows rather than widens in the post-period. The informal and inactive interactions were not robust. Together, the level differential and post-period divergence describe a region experiencing rising pressure as it sends an ever-larger share of its workforce abroad.

The temporal dynamics of the high-exposure external-migration differential are presented in Figure 2. Prior to 2016, the estimates were small, but in 2018 the gap widened sharply to approximately 3.65 percentage points, rising to 5.74% in 2021 and 7.56% in 2023.

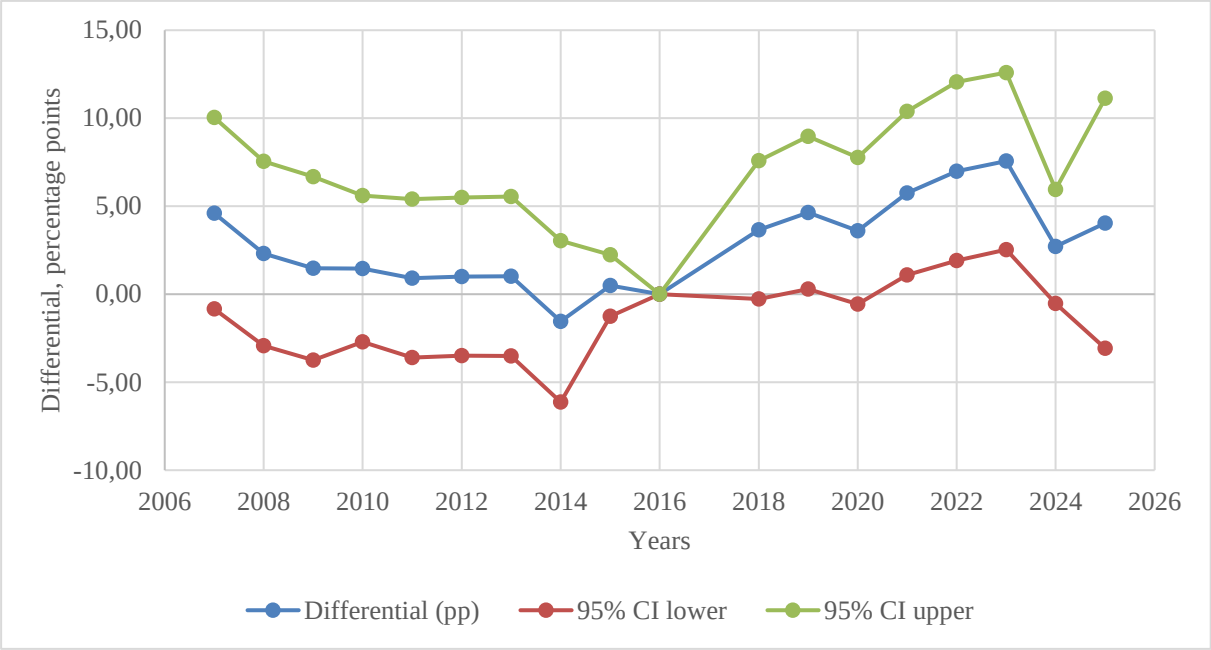


Figure 2. High-exposure differential in external migration (base 2016)
Notes. Event-study estimates of the high-exposure differential in external migration, base year 2016, with 95% confidence intervals. Source: Authors' calculations.

The fourth specification replaces the post indicator with the desiccation index and interacts with exposure. For the high tier, the index coefficient is positive, indicating that external migration increases by about 1.3 percentage points for each additional 10 percentage points of 1960 area lost, with a cluster-robust p-value of 0.052, rising to about 0.18 under the wild cluster bootstrap method. Therefore, we treated it as consistent with the main exposure results, rather than as an independent confirmation. This indicates that more intense drying is associated with a wider migration gap between the exposed and control regions, consistent with the baseline model. We present the estimate as suggestive because the index is basin-wide, and a finer region-year drought measure is needed to support this claim further. Again, the medium tier has a negative coefficient, consistent with Navoi's industrial profile.

Since the post-period begins when national labor statistics are reformed, we check that the divergence is not an accounting artifact. Table 5 presents the post-crisis high-exposure coefficient for external migration across the four sample choices.

Table 5. Robustness of the high-exposure post-period coefficient for external migration

Sample	Coef. (pp)	p cluster	p bootstrap
Full sample, post from 2018	+3.34	0.000	0.101
Drop 2018	+3.56	0.000	0.096
Post from 2019, exclude 2018	+3.56	0.000	0.090
Clean 2007-2016 versus 2019-2025	+3.56	0.000	0.098

Notes. Two-way fixed-effects models with region and year fixed effects. The year 2017 was excluded from this panel. Inference follows the same procedure as in Table 3.

It was 3.34 percentage points for the full sample and 3.56 percentage points when 2018 was excluded. Shifting the post-period to 2019 and excluding the transition years again gives 3.56 percentage points, as does restricting the sample to the pure pre-crisis years of 2007 to 2016 and the pure post-crisis years of 2019 to 2025. The coefficient does not fall when the year of reform is removed. It increases slightly; bootstrap p-values are 0.090–0.098 in the restricted

samples, compared with 0.101 in the full sample, indicating limited support around the 10% threshold. This pattern makes it unlikely that the 2018 methodological change alone drove the observed divergence.

The results provide suggestive support for H1. For the high-exposure group, the migration differential is positive, whereas the differentials for unemployment, inactivity, and informal employment are not robust under bootstrap inference. This pattern is consistent with H2, but differences in statistical significance do not constitute a direct test of differences between outcome coefficients. Migration is therefore the main empirical focus; insignificant estimates for other outcomes do not establish the absence of effects. Navoi is an exception because the mining industry is the only source of employment for local workers and limits the level of informal employment.

The migration results also reflect broad structural changes in the economy. The share of agriculture in total employment fell from 26.8% in 2010 to 21.0% in 2025, while the service sector share rose from 50.5% to 56.7%. Each region must now redirect labor that agriculture no longer needs. Regions with a developed labor market can move these workers into services, but in weak delta regions, most go abroad. The national shift away from agriculture therefore fuels regional-level external migration and tests how well each region can absorb its own labor.

Kazakhstan also experienced a second crisis in the same basin. Kyzylorda lies downstream of the Syr Darya along the Aral Sea's northern shore and is classified as a major ecological disaster zone. This allows us to determine whether a similar structural profile holds. Table 6 compares Kyzylorda with two non-Aral migration benchmarks and national averages.

Table 6. Net migration and labor-market indicators in Kazakhstan, Aral-exposed and benchmark regions

Region	Net migration	Rural share, %	Agric. emp.	GRP per head 2023, th. tenge
Kyzylorda (exposed)	Negative	53	High	3,072
Turkestan (agrarian)	Negative	majority	High	1,798
Atyrau (resource)	Positive	low	Low	21,813
Almaty city (services)	Strongly positive	0	Low	11,493
Kazakhstan (national)	Neutral	about 38	11.5%	6,002

Notes. Gross regional product per capita for 2023 is taken from the Bureau of National Statistics of Kazakhstan (2024). Rural population shares and the direction of net migration are based on official regional statistics (Bureau of National Statistics of Kazakhstan, 2026). Because Kazakhstan reports regional net migration, whereas Uzbekistan reports the number of workers employed abroad, the Kazakh figures are presented only for structural comparison and are not used in the econometric analysis.

Kyzylorda's per capita gross regional product is below the national average, and it ranks 17th among the 20 regions reported for 2023. It remains predominantly rural, with approximately 53% of its population living in rural areas, and it records net population outflow. Census-based evidence also shows that only 8.9% of its population consisted of internal migrants who moved to the region between 2009 and 2021, far below the shares recorded in the main urban growth centers (Eurasian Research Institute, 2024).

Uzbekistan exports labor abroad, while Kazakhstan reallocates it internally among its growth centers. In both countries, the exposed region adjusts by sending people to other labor markets rather than absorbing them at home. The Kazakh evidence provides a directionally consistent answer to RQ2, but it should be interpreted as a structural comparison rather than as an independent econometric test. However, labor markets are similar, and low incomes and job

shortages in affected areas push workers to move out. The state can restore part of the sea. However, a policy to ensure employment for the surrounding population remains important.

Because the high-exposure tier contains only two regions, the migration gap is assessed using a randomization test rather than relying solely on cluster asymptotics. We treated each of the 91 possible regional pairs as a placebo high-exposure group, and re-estimated the model for each. The actual Karakalpakstan and Khorezm estimates, at approximately 3.4 percentage points, are the second-largest among the 91 estimates, with two-sided and one-sided permutation p-values of 0.055 and 0.022, respectively. Almost no random pairing reproduces this large gap, addressing the concern that standard or bootstrap errors are fragile when two clusters are treated as existing clusters. The wild cluster bootstrap agrees at 0.082 under Rademacher weights and 0.11 under Webb weights.

The gap did not rest in either region. Dropping Karakalpakstan leaves an estimate of 3.79 percentage points, and dropping Khorezm leaves 2.90 percentage points, both close to the headline figure and still precisely estimated. This result reflects the two exposed regions together rather than a single influential case.

Two additional tests helped explain the results. A joint test of the event-study coefficients up to 2017 rejects the parallel pre-crisis trends hypothesis, as the most vulnerable regions had slightly higher outward migration rates in the earliest years of the sample, before their trajectories converged in the mid-2010s. A synthetic control method, constructed for each exposed region using low-vulnerability potential donors, accurately reproduced pre-crisis dynamics through 2017 but did not allow us to statistically distinguish vulnerable regions from placebo donors after 2017, as outward migration increased nationwide during these years. Therefore, we interpret our findings as consistent interregional differences in outward migration rates rather than a purely region-specific causal effect, which aligns with our study design and the limitations described below.

4. Discussion

The main result suggests higher outward labor mobility in the most exposed parts of the Aral Sea region, with limited bootstrap support. Karakalpakstan and Khorezm have a larger share of their economically active population working abroad, while unemployment, informal employment, and inactivity show no robust differentials. This matters because environmental stress can be obscured in standard labor market statistics when workers leave before they are recorded as unemployed. In this sense, migration is not only a demographic outcome. It may be part of the regional adaptation process.

The broader implication is that unemployment may be an incomplete indicator of regional vulnerability under environmental stress. In regions with established mobility networks, ecological pressure can be externalized through labor outflows, leaving conventional unemployment indicators comparatively stable. Similar mechanisms may arise in drought-prone agricultural zones, shrinking inland-water basins, salinized delta regions, and other territories where environmental degradation reduces local productive capacity faster than alternative employment can be created.

Recent evidence shows that environmental degradation can reduce agricultural productivity and redirect labor across sectors and regions (Afridi et al., 2022; Colmer, 2021; Fishman & Li, 2022; Huang et al., 2020). Migration is one possible response, but its scale and direction depend on agricultural exposure, local employment opportunities, migration networks, household resources, and the severity of environmental pressure (Caretta et al., 2023; Helbling & Meierrieks, 2021; Hoffmann et al., 2020; Thalheimer et al., 2022). This evidence extends the foundational interpretation of migration as adaptation, proposed by McLeman and

Smit (2006) and Black et al. (2011), by showing that mobility is contingent on regional absorptive capacity and household vulnerability.

The same pattern appears in other climate-vulnerable areas, where agriculture cannot absorb released labor and mobility takes its place, as in rural China (Huang et al., 2020), South Asia (Afridi et al., 2022), and sub-Saharan Africa (Agamile et al., 2021). In each case, including the Aral Sea Basin, degradation shifts labor through migration rather than causing a lasting rise in local unemployment.

The Aral Sea case clearly shows how environmental pressures translate into labor market outcomes through a chain of regional adaptation mechanisms. The shrinking Aral Sea reduces water security, increases soil salinity, and increases the frequency of dust storms, undermining the delta's agricultural economy. This process does not automatically increase open unemployment, as many households respond to the crisis before job losses are officially recorded.

In Karakalpakstan and Khorezm, limited local demand outside agriculture means the local service sector and industry cannot fully absorb the displaced labor force. As a result, adaptation occurs in the form of external mobility. Migration becomes a strategy for households to maintain income levels and, at the same time, a regional mechanism for reducing the burden on a local economy that cannot create enough alternative jobs. This interpretation aligns with the broader literature on climate-driven mobility, but the Aral Sea basin shows a specific regional mechanism in which long-term environmental degradation is refracted through the local labor market's weak absorptive capacity and established migration networks.

These results are important for developing measures to help the region adapt to this crisis and ensure the population's future in the Aral Sea basin. It is not correct to view population labor migration solely as a negative, unsuccessful state policy. In the most affected regions, labor migration is the most acceptable solution for the population to address these environmental and economic consequences (World Bank, 2023).

Therefore, regional policy should combine four key elements. First, monitoring labor mobility must improve, including tracking the share of workers abroad, the degree of remittance dependence, and the vulnerability of migrant families. Second, migrants' rights protection should be strengthened by introducing formal employment contracts, ensuring access to social security, and creating safer employment channels. Research on highly skilled migrants suggests that digitalization and remote-working technologies can support professional integration, although excessive reliance on remote interaction may also create risks of digital isolation (Tutar & Bilan, 2026). These findings suggest that digital employment channels should complement, rather than replace, broader social integration measures. Third, investments in alternative income sources in rural areas outside the agricultural sector are essential to ensure migration becomes a conscious choice rather than the only option. Fourth, continued support for water-saving technologies in agriculture, restoring degraded lands, and greening exposed seabeds is essential. Research on organizational digital transformation highlights the importance of clear communication, trust in digital systems, and perceived control in shaping employee engagement (Hernik et al., 2025). By analogy, technology-based adaptation initiatives in environmentally stressed regions should consider user engagement alongside technical implementation.

Taken together, these measures will link labor mobility with environmental adaptation and make regional policies more responsive to the social consequences of environmental degradation.

This study has several limitations. The level of environmental impact is measured primarily based on geographic location and the Generalized Basin Desiccation Index. These indicators capture long-term environmental pressures, but they do not isolate the impact of

specific short-term shocks such as isolated droughts, dust storms, or sharp increases in soil salinity. The high-exposure group also includes only two regions, so the estimates should be read as evidence of a regional adjustment pattern rather than a precise causal effect of a single environmental event. Future work should add annual regional indicators of water availability, soil salinity, dust exposure, vegetation loss, and agricultural productivity. Therefore, the chosen study design allows qualitative identification of differences in adjustment mechanisms but does not establish the causal effect of a specific measured shock in isolation. The desiccation index was calculated for the basin regions as a whole, and the high-exposure group included only two regions. We relied on statistical inferences using the wild-cluster bootstrap method. However, the small number of clusters requires caution in interpretation.

Future research should focus on creating a regional-temporal ecological dataset that includes indicators of drought intensity, soil salinity, dust-storm impact, water availability, and agricultural productivity. This would replace geographic rankings with a precise assessment of stress intensity. Furthermore, expanding the dataset to the entire Aral Sea Basin will let us test whether a common adaptation model applies here and whether national institutions are shaping fundamentally different development trajectories.

These results also speak to regional adaptation planning. Outward migration alone cannot restore the affected landscapes or keep communities in place. Lasting adaptation requires new sources of work outside agriculture to absorb the labor that a shrinking farm sector no longer needs.

Overall, the discussion changes how we read the Aral crisis. It is an environmental and public health disaster, but also a long-term reallocation of regional labor, in which the most exposed regions adapt by sending out labor rather than accumulating unemployment at home.

Conclusion

This article provides suggestive evidence that outward mobility is associated with long-term environmental exposure, while robust differences in unemployment are not detected. Where agriculture is weakened and local non-farm sectors have limited capacity to absorb displaced workers, migration becomes both a household adaptation strategy and a regional adjustment mechanism.

Evidence from the Aral Sea Basin illustrates this broader process. The most environmentally exposed regions rely more heavily on labor outflows, while estimates for unemployment, informal employment, and inactivity are not robust under bootstrap inference. These results do not establish the absence of other adjustment channels or a causal effect of environmental degradation. A structural comparison across the transboundary basin suggests that migrants' destinations differ according to national labor-market institutions, but the underlying mechanism is similar.

The key policy implication is that adaptation measures in the Aral Sea basin must integrate environmental restoration with labor market planning. Since mobility has already become an integral part of household adaptation, the state should make migration processes safer and more formal rather than ignore or deter them.

At the same time, reducing forced migration requires creating more sustainable local alternatives. Introducing water-saving technologies in agriculture, restoring degraded lands, and developing small-scale processing, services, and other non-farm activities can help absorb labor that the traditional agricultural sector no longer fully supports. In this context, regional adaptation policy must protect mobile workers while also creating conditions for more people to remain in the region of their own choice.

This study has three key limitations. The exposure measure was purely geographical and time-invariant. The desiccation index was calculated for the basin as a whole, and the high-exposure group included only two regions. Therefore, the results describe differences in adaptation mechanisms across vulnerability levels rather than a direct causal effect. Combining the Labor Resources Balance data and expanding the panel to the entire basin will allow for a more precise determination of the profiles of citizens who are leaving and those who are staying, as well as test the applicability of a unified adaptation model for this entire transboundary region.

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