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Group Model Building with Rural Youth for Social Ecological Systems in Karakalpakstan

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ABSTRACT

This paper describes the outcomes of a research aimed to assess the viability of Group Model Building (GMB) to catch the environmental degradation challenges in the Republic of Karakalpakstan (Uzbekistan) from the perspective of rural youth. In terms of methodology and approach, the corresponding workshops were conducted with 53 high school students in Janbasqala Village to map local factors affecting water quality and access. The Social Ecological Systems (SES) framework was applied as the working theory. The study's preliminary results indicate the need for a multi-faceted intervention to address current farming practices and water consumption trends. In this context, the GMB approach acted as a platform to train the youth in systems thinking and elicit their views regarding causal relationships and feedback loops contributing to their everyday challenges. The investigation was limited by the short time commitment allotted and the focus on only a youth cohort. The findings support the viability of using GMB for environmental education and capacity-building in resource-constrained rural settings. The social implications are that GMB fosters ecological awareness and cohesion among youth, helping them articulate pathways for community-based adaptation and innovation. The mapping indicates the general trends of solastalgia negatively affecting the SES adaptability. The study has uniquely utilized GMB as a participatory research method with youth in the Aral Sea Basin, mapping how local perceptions of water and land degradation can inform SES resilience strategies, as well as has explored how solastalgia may be a factor in human-nature relations.

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1. Introduction

1.1. The Aral Region

Once one of the world's most immense inland water bodies, the Aral Sea is now 10% of its former size due to the unsustainable use of water from its two major tributaries, i.e. Amu Darya and Syr Darya Rivers, for agricultural purposes (Micklin, 2010). The urgency of the situation is underscored by the fact that during the early 1960s, the lake occupied around 67,500 km2, making it the fourth largest on the planet (Deliry et al., 2020). Soil deterioration, desertification, water scarcity, and biodiversity loss threaten the sustainability of natural resources in the surrounding region. Detrimental ecological factors resulting from desertification, water salinization, and extended heat waves significantly contribute to preventable diseases like anemia, asthma, and cancer (White, 2013).

As Jarylkasinova & Mavlyanov (2020) note, nearly 85% of children under 16 and around 80% of reproductiveage women in Karakalpakstan suffer from anemia due to folic acid and iron deficiencies. Reports of tuberculosis in the region are likewise twice the national average. Alongside a decline in economic opportunities, climate change manifests the primary reason for the emigration of Karakalpaks to nearby Kazakhstan or Russia in recent years (United Nations, 2017).

In light of the escalating climate crisis, this paper explores how participatory modelling exercises can contribute to unravelling the variables involved and simultaneously motivate community engagement with potential solutions.

1.2. Theoretical framework

The Social-Ecological Systems (SES) framework comprises interacting subsystems for natural processes, institutional governance, and resource users. It remains one of the most empirically applied and cited conceptual models because of its adaptability and flexibility in diverse social contexts. It employs nested subsystems of resource units, governance structures, actors, and users, all interconnected within socio-economic and political ecosystems (McGinnis & Ostrom, 2014).

Understanding the vulnerability and assessing the consequences of climate change is key to SES analysis. Vulnerability refers to a community's capacity to adapt to various scenarios of climate-related hazards. The International Panel on Climate Change (IPCC) defines vulnerability "as a function of exposure, sensitivity, and adaptive capacity V = f (E,S,C)." (Lam et al., 2014, p. 474). A more nuanced study of vulnerability within SESs considers how existing power relations, cultural practices, and social psychology affect the behavior of a dynamic nonlinear system (Andries et al., 2004). There is a growing consensus that vulnerability should also encompass social factors that amplify the hazards of environmental degradation to human and natural systems, such as inequality, marginalization, and access to healthcare.

The resilience factor in a SES is its adaptive capacity to diminish vulnerability faced by climate-affected populations. This implies that more resilient social-ecological systems can absorb shocks and reorganize without compromising their basic structure (Leslie & McCabe, 2013; Czucz et al., 2011; Folke et al., 2002). Resilience-building measures such as community engagement, leadership training, community empowerment, and advocacy can boost the capacity of a SES (NASEM, 2019).

Within this framework, this research additionally suggests solastalgia as a threat to an SES's resilience. Solastalgia is a mental health diagnosis for personal distress caused by the deterioration of one's native ecosystem (Albrecht, 2005). In areas of rapid ecological degradation, like the Aral Sea Region, Lake Urmia area, or the Colorado Basin, solastalgia may become pervasive across an entire community. Alterations in familiar landscapes, threats to traditional livelihoods, and deteriorating quality of life affect these SESs' ability to enhance adaptive potency toward shocks and vulnerabilities.

1.3. Group Model Building

Group Model Building (GMB) is a method for analyzing the behavior of complex systems allowing to zero in on causal connections through participatory research via the lens of community-based system dynamics (Hovmand, 2014). This approach involves participants as expert stakeholders by encouraging systems thinking and emphasizing the cause-and-effect relationship of the group-elicited variables. It requires a facilitation team of minimum three serving the distinct roles of lead facilitator, note taker, and modeler (Rich et al., 2018). In this project, the authors utilized GMB to elicit causal maps and combine them in a system dynamics model to define ideas for a shared problem understanding. Many studies have applied GMB as a non-linear methodology to apprehend sophisticated socio-economic and environmental issues, as well as specify interventions in system dynamics (Hernantes et al., 2012; Hovmand, 2014).

GMB is a process of focusing group discussions organized by a series of "scripts" and phases in the facilitation process, helping participants draft a model. This participatory process renders a practical means of building a shared understanding and common ownership of 'wicked problems' in the system (Luna-Reyes et al., 2006). Wicked problems are self-perpetuating and intertwined challenges to a system's resilience that are hard to pinpoint and resolve (Craig, 2020). GMB employs participatory modelling as a collective method of research that reveals complex relations among stakeholders and resources involved in a wicked problem, motivating unexpected approaches to their solution.

In this sense, GMB is an action research process, since it empowers participants to formulate a problem and identify potential solutions through participatory learning and commitment based on a shared vision in mediated modelling. The dynamic behavior of system elements is communicated through causal loop diagrams (CLDs), which visualize relationships between and among variables, loops, and trends. The final CLD is not necessarily the most accurate or exhaustive mapping of a given system, but rather a co-created baseline for further modeling (Hamza et al., 2014; Hovmand, 2014). In this way, GMB exercises help non-experts grasp overall system dynamics through a method with a low barrier to entry (Hovmand, 2014).

1.4 Objectives

In Janbasqala, a rural community facing water scarcity, the study team inquired about the validity of GMB as both a research and education method. The authors sought to understand how GMB training can be adapted for high schoolers as a method for: i.) spurring interest in environmental advocacy; ii.) capacity building in framing local challenges as an SES, and iii.) understanding the wicked problem of water access from the youth's perspective. Specifically, the authors made the attempt to dissect the problem into its underlying variables and their relationships.

In rural communities in Karakalpakstan, like Janbasqala, high schoolers are actively integrated into small-scale farming and directly affected by water scarcity, as it relates to public health and soil quality.

The paper provides a brief survey of the GMB exercises employed and an aggregate map of the factors the participants identified. The map was categorized by thematic domains, and the key loops were identified. The data were then used to assess how GMB could serve as an educational method and to analyze the SES's wicked problem of water scarcity. The hypothesis was that the problem was a reflection of solastalgia, for which GMB's mode of community engagement presented a potential solution.

2. Methods and materials

The goal of the GMB workshops was not a holistic assessment of the community's views, but rather to gauge the young generation's understanding of the issue. The trainers focused on building a general grasp of the Social-Ecological System via case studies and activities from the GMB Scriptopedia. All lessons were centered on the theme of water access.

The exercises were conducted in two schools in Janbasqala, a remote village 70 km from the regional center bordering the encroaching desert. It is a new settlement primarily populated by Kazakh and Turkmen ethnic groups. Fifty-three students participated in a 10-day group model-building training. Of the students, 20 were males, and 33 were females, ranging between 14 and 17 years old. The facilitation team consisted of the co-authors and two research interns. The study team utilized a systems analysis approach that followed a structured participatory method in five distinct phases:

1. Hopes & Fears: Participants were asked to identify key variables as desirable outcomes and potential risks in water access inside the SES (Fig. 1). That activity gauged the participants' attitudes towards environmental degradation and created a collaborative atmosphere.
2. Graphs Over Time: Participants refined the dynamic behavior of a single variable by drafting its time series under various scenarios and interventions (Fig. 5). That helped them systematically consider the long-term implications of their decisions and interventions.
3. Prioritization Using Dots: Participants used stickers to rank the preliminary variables by importance. Each participant identified his/her top three variables (Fig. 2).
4. Connection Circles: The cognitive mapping activity enabled participants to think systemically about the causes and consequences of water scarcity and soil degradation (Fig. 3). The students connected the variables in positive and negative causalities along a circle.
5. Causal Loop Diagrams: The participants mapped variables' interaction over time and their emergent behaviors (Fig. 4). The high school students thus visualized the complex dynamics of their local SES in reinforcing (positive) and balancing (negative) feedback loops, as well as identifying corresponding interventions (Zhang et al., 2019).

The curriculum methodology was assessed via four consecutive surveys at different stages of the GMB workshop between March and May 2023. The surveys evaluated students' retention of concepts in systems dynamics and their motivation to address local environmental concerns. In the year following the workshop, formal interviews were conducted with parents and teachers to triangulate and cross-reference the variables, linkages, and interventions proposed by the students. In January 2024, a follow-up focus group was held with the target high school students to assess ex-post behavioral changes among the cohort.

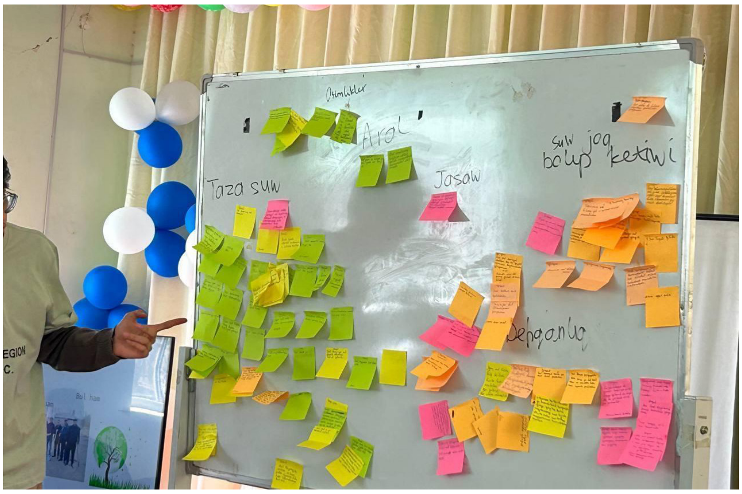

Figure 1. Phase 1: Hopes and Fears.

Figure 2. Phase 2: Prioritization Using Dots.

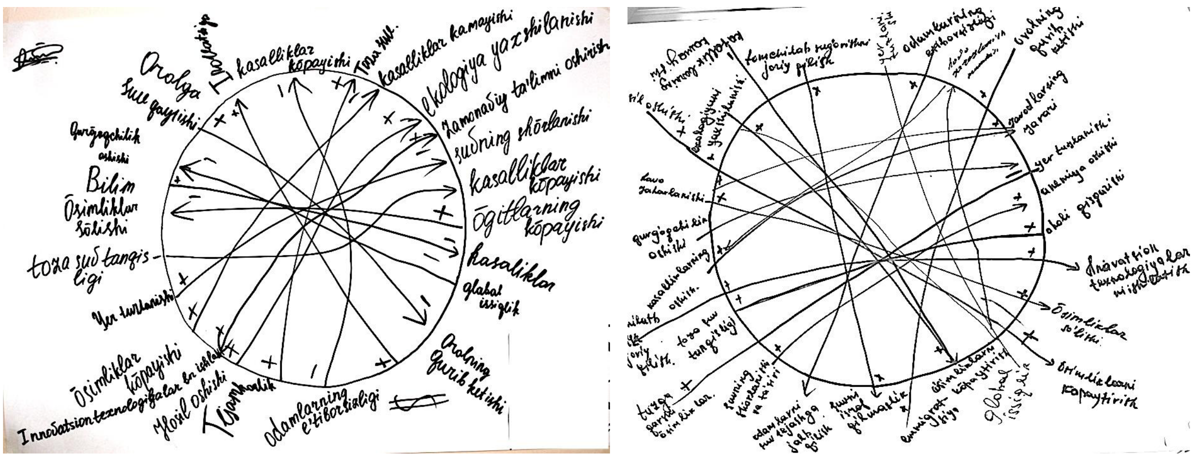

Figure 3. Phase 3: Connection Circles.

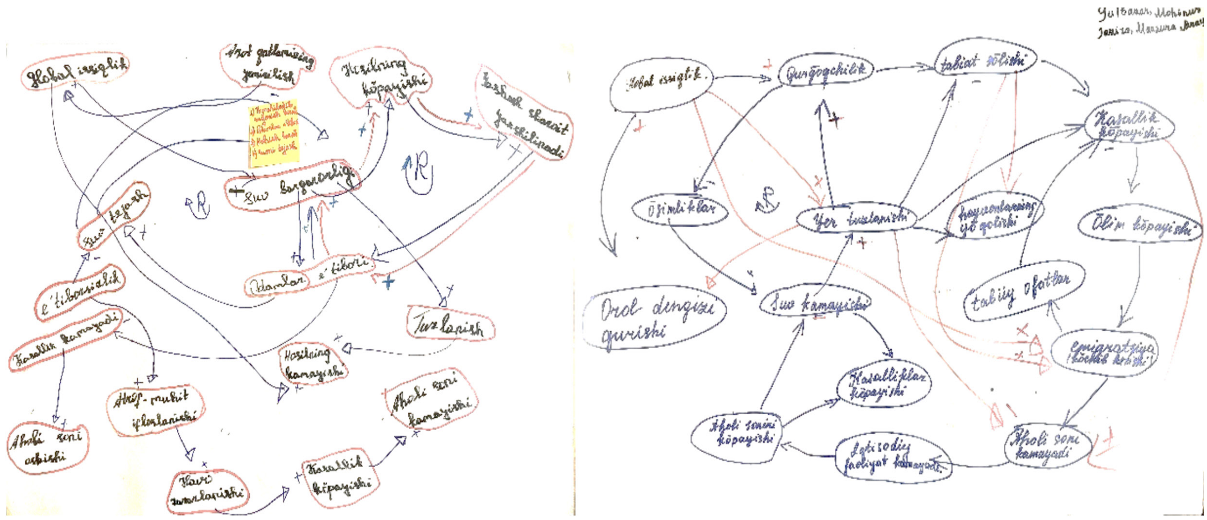

Figure 4. Phase 4: Causal Loop Diagrams.

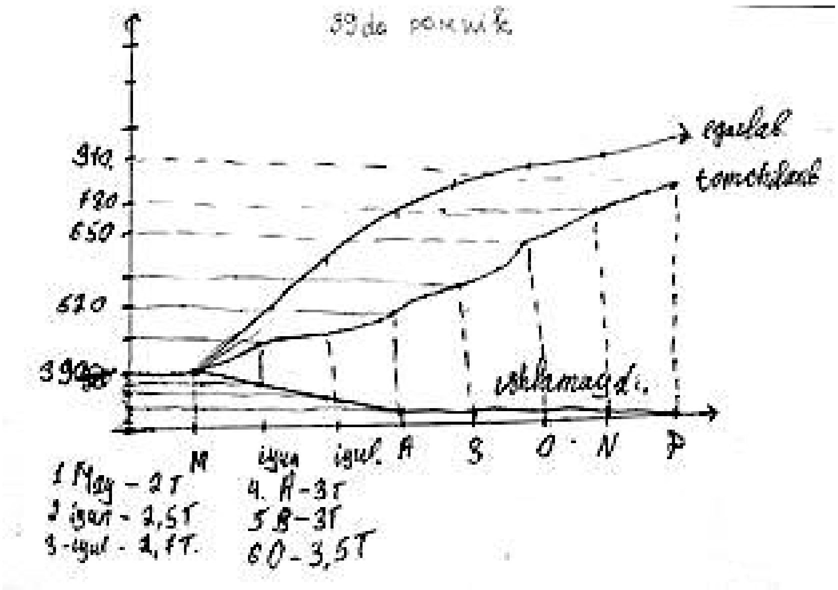

Figure 5. Phase 5: Graphs Over Time.

The group model-building workshop first identified 22 variables in “Hopes and Fears,” that were later ranked by importance during the “Prioritization” exercise. In subsequent teams, students drew 9 connection circle maps and drafted 13 causal loop diagrams. Team sizes varied in the following two exercises, resulting in a differing amount of diagrams. The variables and interlinkages the high school students identified were categorized and combined into a single causal loop diagram, translated into English from Uzbek and Kazakh.

The interventions and feedback loops identified by the students were included in the final causal loop diagram (CLD) in Fig. 6, featuring the most frequently identified variables and relationships. Repeated variables were included only once within the mapping using the Vensim software tool. The high school students' responses were compared to a survey conducted among 30 other members of the Janbasqala community, 18 years and older, as an approximated benchmark.

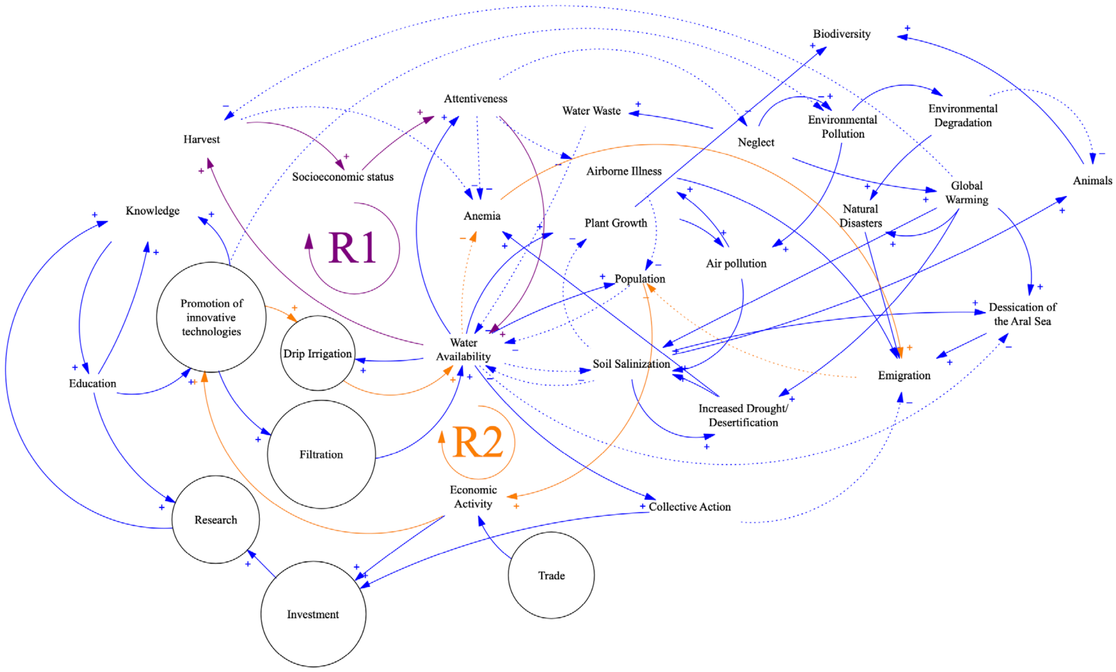

Figure 6. Overall Causal Loop Diagram of the Janbasqala SES (solid lines signify positive correlation; dotted lines signify negative correlation; two key reinforcing feedback loops are labeled R1, in purple, and R2, in orange).

3. Results

The high school participants used GMB methodology to understand their local SES's vulnerabilities. According to their causal loop diagrams, the fall in water availability from the Amu Darya had amplified the adverse effect of seasonal leaching practices, leading to soil and irrigation water salinization. In turn, that affected the quality of potable water in aquifers and heightened the risk of illnesses. Hence, the students linked the variable soil salinization to anemia, as shown by Jarylkasinova & Mavlyanov (2020) and White (2013).

Low water supply has been forcing Janbasqala communities to order water tankers from the upstream regional center of Turtkul for $10/ton. In many areas of Uzbekistan, irrigation water is government-subsidized, but drinking water poses an additional expense, ranging between 300 and 500 UZS/liter.

The students also highlighted social leverage points for adaptive capacity – research, knowledge, and education positively reinforce each other, as well as contribute to designing new techniques and technologies that may allocate water more efficiently.

Emigration turned out the most interconnected sociological variable within the CLD. The high school students identified anemia, airborne illnesses, natural disasters, decline in harvest, and environmental degradation as the "push factors" for emigration. Conversely, they viewed collective action as a "social glue" within their community mitigating the "push factors."

3.1 Analysis by domain

Akin to Groundstroem and Juhola (2021), the map may be further analyzed sectorally (Fig. 7). Table 1 lists all the variables mentioned in five GMB exercises categorized by domain.

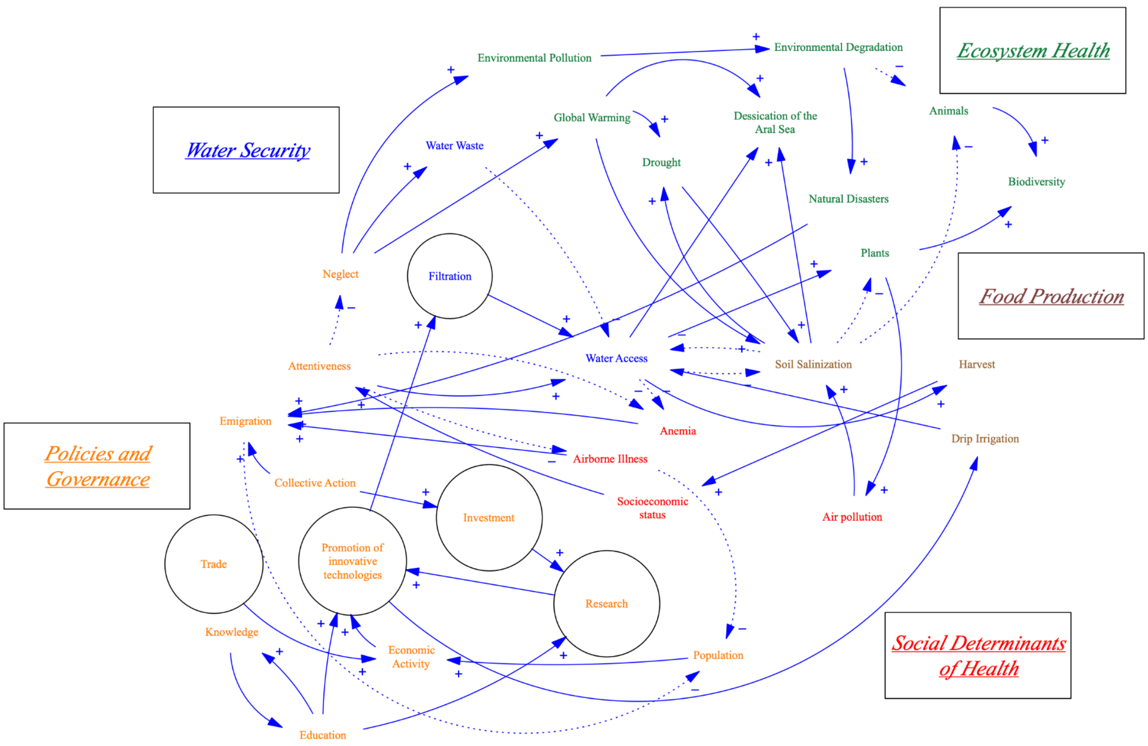

Figure 7. Causal Loop Diagram by domains
(variables re-arranged into five interacting domains of the SES with water at the primary resource).

Table 1. Categorizations of variables into domains.

Ecosystem health	Food production	Policies & governance	Social determinants of health	Water security
Animals; Climate conditions; Deforestation; Drying of the Aral Sea; Ecological pollution; Ecosystem health; Effect on nature and birds; Global warming; Natural disasters; Plants; Poaching; Return of Water to the Aral Sea; Rubbish; Salinization; Salt-resistant plants; Saxaul trees; Trees	Desertification; Drip irrigation; Fertilizers; Harvest; Irrigation; Plant wilting; Soil salinization	Access to tools; Anger; Business growth; Collaboration; Saving resources; Education; Electric cars; Factories; Illnesses; Immigration; Innovation; Innovative technology; Knowledge; Money; New technologies; People's neglect; Recycling; Roads; Trash collection and disposal; Working together	Air pollution; Anemia; Chemical pollution from factories; Dust and sandstorms; Ecological pollution; Illnesses; People getting shorter; Population; Sicknesses	Drought; Fresh water; Not wasting water; Participation in water saving; Return of water to the Aral Sea; Water; Water deficiency; Water salinity; Water waste

"Water Security" represented the variables affecting water availability and access. Access was determined by the volumetric water supply (aquifer, surface, and utilities), and its quality. Filtration was identified as a viable intervention. In the students' CLD, most variables with a causal effect on water security fell in the "Policies and Governance" domain. Water, in turn, affected the "Social Determinants of Health", "Food Production", and "Ecosystem Health" domains, that fed back into the "Policies and Government" variables.

The variables under "Policies and Governance" represented the social infrastructure for managing resources within the SES and related emergent effects, which aligns with Andries' (2004) conception of an SES. In particular, the high schoolers related economic activity and investment to social patterns of engagement, i.e., attentiveness, collective action, and neglect. The participants discussed how collective action could pool funds for filtration improvements and secure stable water access. Economic activity was likewise a function of the size of the population and the strength of trust networks via collective action. The lack of attentiveness towards sanitation, public health, and pollution could increase illnesses, decreasing the population and its corresponding economic activity. Severe illnesses, as observed in

Karakalpakstan, debilitate non-disabled community members, cut into free income, and push people to emigrate.

The “Social Determinants of Health” included anemia caused by malnutrition and salinization of potable groundwater, and airborne illnesses caused by the inter-mixing of toxic sediment in sandstorms. The community survey corroborated the concerns. Its respondents ranked anemia and water scarcity as the two top issues their community faced. That corresponded to the 2017 region-wide poll conducted by UNICEF, where air and water pollution were the main concerns reported by Karakalpakstan residents (United Nations, 2017).

In the domain of “Ecosystem Health”, depletion of water supplies was linked to degradation of the Aral Region’s biosphere. According to the students, neglect within the community also had a long-term effect on global warming.

The domain of “Food Production” contained variables related to crop production in the target agricultural community, which the high schoolers represented with the harvest variable determined by water access, land quality (soil salinization), and water delivery efficiency (drip irrigation). The effect of harvest, according to the students, was primarily on the socio-economic status, i.e. quality of life. They plotted the relationship as follows: Harvest -(+)-> Socio-economic status -(+)->Attentiveness -(-)-> Neglect -(+)-> Water waste -(-)-> Water access. Greater wealth due to better harvest affected the community’s willingness to be more attentive to ecological concerns.

3.2 Key reinforcing loops

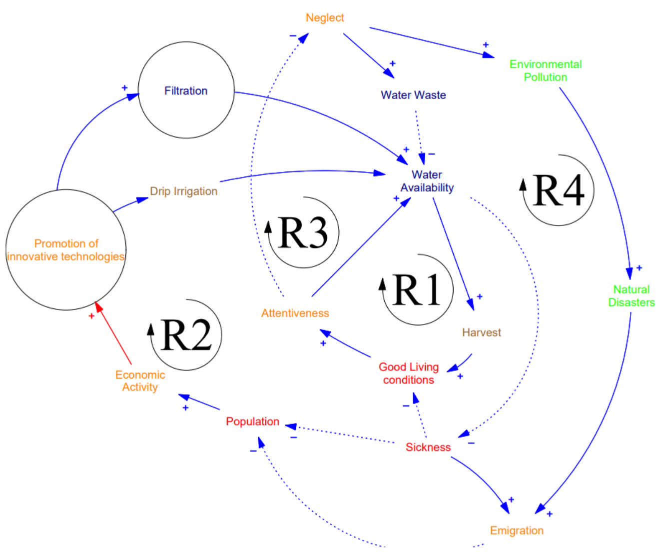

Figure 8. Key SES loops in the Causal Loop Diagram.

In Fig. 8, the high school students’ CLD is isolated to four reinforcing loops mapping falling surface and groundwater quality.

These may be interpreted as long-term trends. The R1 and R2 are the “optimistic” loops, with R3 and R4 as the “wicked” loops. R1 and R2 demonstrate mechanisms that ameliorate access to clean water. According to the high schoolers, the fall in living conditions had brought about the fall in the population's interest in caring for the environment. R3 and R4, as wicked loops, show that environmental neglect reinforces the SES’s vulnerabilities. The loops are summarized in Table 2.

Table 2. Description of reinforcing loops.

R1	Water Availability -(+)-> Harvest -(+)-> Socio-economic status -(+)->Attentiveness -(+)-> Water availability
	The Diagram’s foundational causal loop. Water availability allows for a greater harvest and a higher socio-economic status. A prospering community, in turn, has the time, energy, and psychological support to invest attention in the ecological well-being of their SES, avoiding excessive flood irrigation, for example. This, in turn, enhances water availability.
R2	Promotion of innovative technologies -(+)-> Drip irrigation/filtration -(+)-> Water availability -(-)-> Sicknesses -(-)-> Population -(+)-> Economic activity -(+)-> Promotion of innovative technologies
	This is an “optimistic” positive feedback loop, where investment and promotion of innovations that address water quality and supply allow for greater water access. Hence, fewer sicknesses and a growing robust population. In turn, community’s growth promotes increased economic activity and further research and interest in water-sustainable innovations.
R3	Attentiveness -(-)-> Neglect -(+)-> Water waste -(-)-> Water availability -(+)-> Harvest -(+)-> Good living conditions -(+)-> Attentiveness
	This loop links the population's neglect of the environment with poorer living conditions. The resulting fall in prosperity, as proposed by the high school students, leads to a further fall in attentiveness and neglect. Community members fall into a cycle of learned helplessness and desperation. As a result, they are not interested in improving environmental conditions.
R4	Neglect -(+)-> Environmental pollution -(+)-> Natural disasters -(+)-> Emigration -(-)-> Population -(+)-> Economic activity -(+)-> Promotion of innovative technologies -(+)-> Drip irrigation/filtration -(+)-> Water availability -(+)-> Harvest -(+)-> Good living conditions -(+)-> Attentiveness -(-)-> Neglect
	The loop implies that the environmental hazards provoked by neglect lead to growing emigration. This, in turn, hurts the dwindling population's innovative potential through the loss of intellectual, entrepreneurial, and financial capital. As in loop R3, this leads to desperate communities uninterested in adjusting behaviors and addressing environmental challenges. Instead, as the loop suggests, even more community members choose emigration as the optimal decision.

Table 2 shows a synthesis of the underlying feedback structure and summarizes the proposed leverage points to balance the effects of ecological hazards via sustainable farming and water management. Specific factors such as promoting innovative technologies, drip irrigation, water filtration, and attentiveness, were identified as the potential intervention points. More specifically, the high schoolers identified certain social resilience interventions driven by investment, i.e. healthy rural economies, capacity building in adaptive technologies, and attentiveness to ecosystem needs.

4. Discussion

4.1. Assessing the validity of students' systems thinking

Whereas GMB mappings are traditionally drafted by a cohort of stakeholders with years of experience, the mappers within the framework of this research were younger community members. In assessing GMB as a research method, the study team recognized the limitations of producing a valid SES analysis based on the data produced exclusively by the youth. For example, the aggregate CLD emphasized direct personal agency on natural processes. The variables representing localized factors, like soil salinization and socio-economic status (many students called it good living conditions), intermingled with regional-scale variables, like natural disasters, desiccation of the Aral Sea, and trade. The students argued that local neglect led to environmental pollution, degradation, and natural disasters. In Uzbekistan's context, where decisions in basin management are streamlined towards the center, such a conception indicates the students' idealism. It may also represent an error of scale.

Nevertheless, the students' mapping also indicated an intimate knowledge of their community's challenges within the local SES. For instance, in the connection circles, airborne illnesses were linked to air pollution, ecological degradation, and improper trash disposal. Though often overlooked in the development narrative of ecological degradation in the Aral Sea Basin, waste management challenges were identified as a top concern in multiple rural communities in Uzbekistan (UNDP, 2024). Likewise, the students, many of whose families were small-scale commercial farmers, did not view harvest as a matter of subsistence, but rather as a guarantee of income. Increased income, in turn, could create a robust community capable of mobilizing resources towards a resilient SES in Janbasqala.

Involving a youth cohort with a different generational outlook on the ecological health of their SES, may therefore reveal boundary conditions and feedback loops in the system that older participants would otherwise overlook.

4.2 GMB as an education tool

We hypothesized that GMB could widen young people's boundary conditions in approaching an SES, encouraging them to think more broadly about the factors leading to ecological degradation in their own community. Previous applications of GMB in a school setting – focusing directly on students' educational experiences –

demonstrate how GMB offers young participants new ways for dealing with wicked problems (Trani, 2019; Hovmand, 2014). Applying GMB to teach about water scarcity, this study's team looked at how high-schoolers' perceptions of the problem and motivation to address it changed.

A pre- and post-survey was distributed on March 20 and May 28. It included qualitative and quantitative prompts on systems thinking and readiness to engage in ecological advocacy. Between the start and end of those sessions, on a scale of 1 to 10, the students reported a 2.5-point increase in concern for local ecosystems and a 2.8-point increase in concern for Janbasqala's water resources. The distribution of responses was 99% significant under the heteroskedastic Student t-test. Likewise, the students reported a 1.0-point increase in their self-assessment for the question "How ready are you to create an environmental project to help Janbasqala?"

As shown in Fig. 9, the students reconsidered what activities were relevant for addressing environmental challenges in their community. Whereas in March they had preferred exclusively physical solutions, like planting trees and saving water, in May they noted socially-driven proposals, like mobilizing a team and raising awareness. This suggests that – apart from motivating the students to be more involved in ecological projects – the GMB exercises in Janbasqala Village made the youth consider more, oftentimes less anticipated, factors in water scarcity.

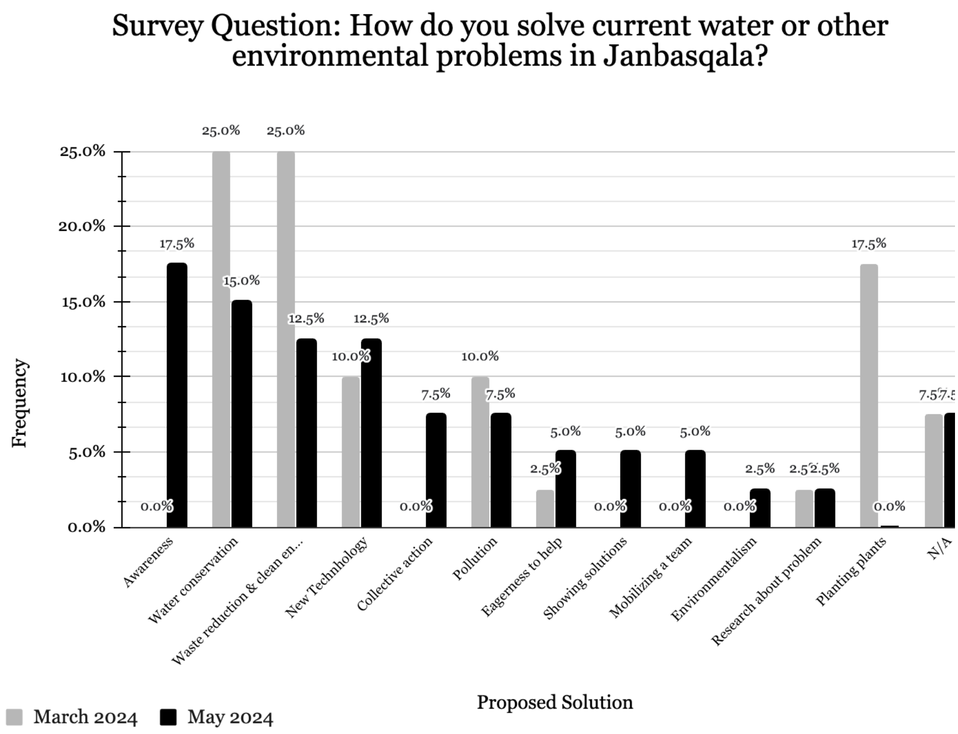

Figure 9. Written participant survey responses.

4.3 Solastalgia and a social psychology-driven perspective

One such unanticipated element is the CLD's suggestion that a community cannot adjust to environmental degradation in conditions of socio-economic adversity and emigration (Fig. 8). When viewed within the SES framework of Andries (2004) and Huggins et al. (2023), this is a symptom of vulnerability characterized by water salinization, soil erosion, and biodiversity loss. These conditions drive farming communities deeper into poverty and push them towards unsustainable agricultural practices contributing to the wicked loop of environmental degradation, and exacerbate climate change effects.

In a similar case study of desertification around Lake Urmia in Iran, Zhenko & Menga (2019) observed how emergent social challenges, including emigration, illegal water abstraction, and heightened resource competition, interacted with escalating ecological degradation. They analyzed such trends through the lens of solastalgia and learned helplessness, when community-wide stress suppresses impulses for ameliorating emergent challenges. The individuals surveyed in the Urmia communities shared feelings of hopelessness, social isolation, and anxiety regarding their livelihoods, health, and the environment. Hopelessness, in turn, fueled neglect, reinforcing a vicious loop of negative behaviors like overexploitation of aquifers, neighbor conflicts, and general apathy toward equitably conserving scarce resources.

In the workshops under this study, the students viewed the psychological aspect of the SES as crucial to resilience. Variables such as neglect and attentiveness were subject of intense discussion amongst the group. The students ranked neglect as the second most important variable, as well as argued for the need to create a motivating environment for water saving on a local scale. Indeed, in Uzbekistan, local farmers have little agency over water distributed to secondary canals and aim to maximize their exploitation of any allocated water (Brite, 2016).

The solastalgia framework also explains the emerging trend of emigration. Zhenko & Menga (2019) described how out-migration weakened existing support networks (informal agreements and extended-family arrangements for water sharing) and economic activity within the community. Since 1995, there has been a wave of emigration from Karakalpakstan, with Kazakhstan as a large recipient of Karakalpak immigrants claiming Kazakh ethnicity. Between 2000 and 2015, climate change-induced resettlement was particularly acute. Recent data (2021-2023) indicate a new emigration uptick (Embergenov et al., 2023). Within one year of the project's commencement, multiple involved families moved to Kazakhstan as a chance to break out of poverty.

The high schoolers identified a relationship between emigration and water-efficient technologies. They argued that emigration curbed economic activity and interest in pooling funds for solutions. While water availability and remittances may certainly grow with emigration, its net result is an outflow of SES's finances, intellectual capital, labor, and other support nodes. As a result, effected communities cannot cope with the escalating degradation of water and soil.

Socio-economic and demographic factors, therefore, drive the key wicked problem in the high schoolers' SES. A thriving population with stable networks of trust and finances is more capable of withstanding systemic and aleatoric shocks to the system's stock and water quality.

As a solution, the students identified economic activity, investment, and harvest as indicators of socio-economic welfare, that could promote resilience via pooled water procurement arrangements, investment in precision irrigation, sustainable desalination techniques, and insurance schemes.

How may stakeholders within the community and policymakers induce the growth of the aforementioned social capital? After 50 years of deteriorating natural and socio-economic conditions, what interventions make sense for solastalgic communities? The high schoolers in this study suggested the interventions of increased investment, research, and economic activity for promoting water-efficient technologies, like precision agriculture and desalination. Such interventions may be viewed as large-scale nationwide policies. Research and investment in water efficiency would trickle down and promote education and development in rural communities like Janbasqala. Indeed, in a 2017 UNDP survey of community needs, the respondents in Karakalpakstan indicated the need for more intensive environmental education (United Nations, 2017).

If the resilience of a SES and the trickle-down of investment projects depend on community motivation and attentiveness, how may it be induced? In answering these questions, the authors consider GMB – particularly with young people just stepping into fully-fledged membership of their communities – as a viable methodology for addressing the challenges and triggering the interventions identified in the CLD (Fig. 6).

Group Model Building, as this study shows, motivated the youth in Janbasqala to reconsider their role and relationship to water. It opened a dialogue on how they personally could assist the community in seeking new opportunities for water-efficient irrigation and mobilize resources towards their implementation. Even more so, GMB should not be implemented as a one-time intervention, but as a continual pedagogical exercise for reinforcing systems thinking among participants. GMB is a template for practical environmental education, with actionable results.

4.4 Limitations

One significant limitation of utilizing GMB with youths in rural Karakalpakstan was the relatively high time spent explaining instructions through an interpreter in Kazakh and Karakalpak languages. That created a risk of both acquiescence and selection bias among the participants and the perception of hierarchy during interactions with adults. The team had to verify that issue through pre-post surveys and focus group discussions to validate youth perspectives on environmental degradation in Janbasqala. There were likewise challenges in implementing connection circles, as the participants quickly realized that the problems may have multiple causes. As such, the concepts of feedback, cause, and dynamic hypothesis as part of the system's thinking had to be reiterated several times. Although the adolescents seemed motivated during the workshops, the GMB process required considerable commitment from the participants, in-depth knowledge of the context, and experienced workshop facilitation (Hovmand, 2014).

Similarly, the project used self-reported perspectives of the participants within one geographic location, making it hard to validate the scope of ecological hazards throughout the region externally. The study is mainly descriptive and does not include computer simulations of system behavior based on the identified leverage points and feedback loops.

While community mobilization and socio-economic wellbeing are associated with sustainable farming practices and water-saving technologies, designing interventions can be difficult without engaging local authorities and adults (Rich et al., 2018). Finally, the participatory research using the GMB process was conducted with youth that resulted in a strong power differential which, despite the team's efforts to give participants independence, influenced the CLD mapping (Hovmand, 2014). Separate GMB sessions with parents and local authorities could enhance the external validity of this study and produce actionable collective interventions.

5. Conclusion

Within the framework of this study, GMB enabled the participants to create a shared mental model and understand the wicked complexity of ecological degradation, along with the ways to mitigate it within a resource-limited environment. The final CLD indicated the need for creating the “right environment” to motivate local interest in saving water, such that technologies and techniques have a more significant staying potential within the community. Socio-economic welfare has to be guaranteed to reap the benefits of exogenous resilience and capacity-building development programs. Otherwise, neglect, emigration, distrust, and helplessness will dampen the gains a project offers.

In addition to socio-economic conditions, the students identified the education variable as another key to positive change in their local SES. Group Model Building, as a method for capacity building and participatory research, offered educational system dynamics that contributed to grassroots innovation and advocacy for rural communities like Janbasqala.

Areas for improvement include the time commitment required for participation in the complete workshop, ensuring the representation of the participant group, and external validation of the causal map with a broader audience that may include parents of the youth and educators. Engaging a wider range of stake-holders could also enhance the design of culturally appropriate and gender-specific interventions.

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