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Allelopathic Responses of Crop Species to *Chromolaena odorata* Root Exudate Extracts: A Comprehensive Study

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Abstract

This study investigates the allelopathic effects of root exudate extracts from *Chromolaena odorata* on the germination and growth of six crop species. The results reveal variable sensitivity among the species, with the control treatment consistently exhibiting superior germination percentages. Initially, some species, including *Abelmoschus esculentus* (okra), *Solanum lycopersicum* (tomato), and *Cicer arietinum* (chickpea), experienced a substantial decline in germination, indicating a potential inhibitory effect of the exudates, although partial recovery was observed in subsequent treatments. *Phaseolus vulgaris* (common bean) displayed a moderate decrease, while *Zea mays* (corn) exhibited the most significant drop in germination rates, albeit with slight recovery at higher concentrations of exudates. Conversely, *Cucumis sativus* (cucumber) appeared least affected by the exudates. Moreover, all species demonstrated reductions in shoot and root lengths with increasing concentrations of exudates. Chlorophyll content analysis revealed a significant reduction across most treatments, highlighting concerns regarding photosynthetic efficiency and overall plant health. The species-specific response to root exudates suggests varying metabolic or adaptive mechanisms among crops. Additionally, malondialdehyde (MDA) levels, indicative of oxidative stress, varied among species, with *A. esculentus* and *P. vulgaris* showing a dose-dependent increase, while *S. lycopersicum* displayed a peak at intermediate treatment levels. *Z. mays* exhibited marginal elevation in MDA content, potentially indicating the presence of protective compounds within the exudates. Conversely, *C. arietinum* and *C. sativus* showed a steady increase in MDA, suggesting limited mitigation of allelopathic effects. These findings feature the complexity of allelopathic interactions and highlight the need for further research into active compounds and their modes of action to develop sustainable weed management strategies while safeguarding crop health. Understanding these dynamics is crucial for maximizing the potential benefits of allelopathy in agriculture.

Keywords

Allelopathy; Root exudates; *Chromolaena odorata*; Crop plants; Seed germination; Chlorophyll content; MDA content
Introduction

Weed management has perennially posed a formidable challenge in agriculture, constituting a significant threat to crop productivity and yield (Storkey et al., 2021). Traditional weed control methods are inefficient, costly, and environmentally harmful (Woyessa, 2022). In response to these challenges, the widespread adoption of herbicides has become a cornerstone of modern agricultural practices (Ofosu et al., 2023). However, concerns regarding herbicide resistance among weed populations, environmental contamination, and potential risks to human health have spurred a critical reevaluation of weed management strategies (Ofosu et al., 2023). The dominance of herbicides in contemporary agriculture reflects their perceived efficacy in selectively targeting and eliminating unwanted plant species while minimizing harm to crops (Kraehmer et al., 2014). Glyphosate, in particular, has emerged as a widely used herbicide due to its broad-spectrum effectiveness and perceived safety (Kanissery et al., 2019). However, the overreliance on herbicides has precipitated several unintended consequences, including the emergence of herbicide-resistant weed biotypes, soil and water contamination, and ecological disruptions (Schütte et al., 2017). Consequently, there is a growing recognition of the need for alternative weed management approaches that prioritize sustainability and environmental stewardship (Chauhan et al., 2017).

Among the emerging paradigms in weed management is the exploration of allelopathy — a natural phenomenon whereby plants release biochemical compounds that inhibits the growth of neighboring plants (Khamare, Chen and Marble, 2022). Allelopathy offers a promising option for sustainable weed management leveraging the allelopathic phenomenon, the synergistic application of allelopathic rhizobacteria (Pseudomonas fluorescens and Bacillus sp.) combined with Sorghum allelopathic extract surpasses conventional weed management practices by efficaciously inhibiting weed proliferation and augmenting wheat productivity, thus emphasizing a viable, sustainable strategy for agricultural weed control (Raza et al., 2021). The allelopathic properties of crops such as rice, wheat, and barley have been extensively studied for their potential to inhibit weed growth and reduce the reliance on herbicides (Khanh et al., 2013).

Integrating allelopathic principles into agricultural practices holds the promise of enhancing both weed management and overall crop productivity (Kostina-Bednarz, Płonka and Barchańska, 2023). By incorporating allelopathic cover crops into crop rotations, farmers can effectively suppress weed growth, improve soil health, and mitigate the environmental impacts associated with herbicide use (Kunz et al., 2016). However, realizing the full potential of allelopathy as a sustainable weed management strategy necessitates addressing several challenges. These include identifying allelopathic plant species with potent and consistent effects on target weeds, understanding the ecological impacts of allele-chemicals on non-target organisms, and facilitating the adoption of allelopathic cropping systems by farmers (Kunz et al., 2016). The scarcity of research into the influence of Chromolaena odorata root exudate on seed germination in Bangladesh is notable. Despite thorough searches in major scientific databases, no dedicated studies have been found concerning this subject. This lack of data highlights a critical gap in our understanding of C. odorata's ecological roles, underlining the originality and significance of our investigation. This study seeks to fill this gap by evaluating the impact of root exudate extracts from Chromolaena odorata on the germination and growth of various vegetable crops. By
conducting detailed analyses, it is aimed to explore the effectiveness of allelopathy as an efficient and eco-friendly weed management strategy in agriculture.

**Materials and Methods**

**Sample Collection**

In order to assess the allelopathic impact of root exudates from certain weed species on the germination and biochemical measurement of crop seedlings, six seeds from various crop species were gathered from local bazar, university campus, University of Chittagong, Hathazari, Bangladesh. Concurrently, *C. odorata* plants at the flowering stage were gathered as donor plants from the botanical garden of the Department of Botany, University of Chittagong.

**Root Exudate Preparation**

Approximately 30 weed species were uprooted from the vicinity of the botanical garden at the University of Chittagong. Each specimen was carefully uprooted, ensuring the preservation of the root structure, followed by a thorough cleansing process involving an initial rinse with tap water and a subsequent rinse with distilled water to remove any adherent soil particles. These cleansed roots were then placed in conical flasks containing 1.2 liter of distilled water for duration of 5 hours (exposed to sunlight), a period during which root exudates were allowed to diffuse into the surrounding medium. To collect these exudates, a vacuum filtration method was employed, ensuring a precise and uncontaminated extraction. For experimental analysis, the filtered exudate was equally divided into three aliquots and placed into separate jars for differential treatment: the first aliquot was maintained at its original concentration (T1), the second was concentrated to 50% of the original volume (T2), and the third was further concentrated to 25% of the initial volume (T3). These prepared samples were then stored in a refrigerator to preserve their integrity for subsequent analytical procedures (Akter *et al.*, 2023; Alsherif *et al.* 2013).

**Method for Petri Dish Setup and Bioassay**

Seeds were picked based on their uniform size, shape, color, and health before being sterilized in 70% ethanol for 1-2 min and then washed five times with sterile distilled water to wash away the chemical (Deepak and Virk, 2022). For the soil experiment, petri dish filled with garden soil collected from botanical garden, University of Chittagong, and 10 seeds were planted and irrigated with 5 mL of aqueous root exudates accordingly. The control receives the same amount of water. The growth chamber was kept at a constant temperature of 25°C, and moisture where the petri dish and other containers were left. When the radicle length reached more than 2 mm, it was determined that the seed had germinated. After 14 days, germination indicators were measured, such as the number of seeds that germinated the length of the roots and shoots, and the weight of the seedlings (Figure 1) (Iman *et al.*, 2006).
Figure 1: Flow diagram of root exudate collection and bioassay
**Quantifying Lipid Peroxidation (LPO)**

The LPO method, derived from Högb erg *et al.* (1974), involved weighing tissue samples (1 g) and homogenizing them in 0.15 mol/L cold KCl. The volume was adjusted to 2 mL with 0.3 M Tris-HCl buffer (pH 7.4) and 0.02 mM sodium pyrophosphate. After 37°C incubation for 30 minutes, 10% trichloroacetic acid (1 mL) was added to halt the reaction, followed by vortexing. Thiobarbituric acid (1.5 mL) was then introduced, and samples were heated for 20 minutes in a boiling water bath, repeated thrice. Post-centrifugation, spectrophotometric measurement at 532 nm quantified malondialdehyde levels, indicative of lipid peroxidation (nmol MDA/mg protein).

**Statistical Analysis**

Statistical analysis involved three repetitions of data analysis using Microsoft Excel 2010 and GraphPad Prism Data Editor for Windows, Version 8.4.3. Analytical techniques encompassed Dunnett's test, one-way, and two-way ANOVA. Results, depicted as mean ± Standard Error of Mean (SEM), were considered significant at p < 0.05 (Akter *et al.*, 2023).

**Results**

**Germination Dynamics**

The germinative response of six vegetable species to *C. odorata* root exudates was characterized by variable sensitivity, as demonstrated in figure 2. The control treatment (T0) typically exhibited superior germination percentages, suggesting a latent inhibitory potential in the exudates. Initially, *A. esculentus*, *S. lycopersicum*, and *C. arietinum* show a substantial decline in germination at T1 (below 40%), indicating a potential inhibitory effect of the exudates. However, their germination rates partially recover in subsequent treatments, suggesting some level of adaptation or tolerance (Figure 1). *P. vulgaris* displays a moderate decrease throughout the treatments, maintaining almost half of its initial germination rate by T3 (46.70%). *Z. mays* experiences the most significant drop at T1 (30%) and T2 (26.70%) but shows a slight recovery at T3 (36.70%), which may indicate a non-linear response to the exudate concentrations. *C. sativus* appears to be the least affected, with a high germination rate at T1 (80%), only a moderate decline at T2 (60%), and a near return to its initial rate at T3 (70%).

**Effect on Shoot and Root Growth**

In table 1 and 2 showed the shoot and root length reduction in all species with the introduction of *C. odorata* exudates, as compared to the control. For example, *A. esculentus* showed a pronounced decrease from 20.22±0.08 cm in the control to 7.25±0.08 cm in T3, the highest concentration of exudates. Similarly, *S. lycopersicum* exhibited a reduction from 5.42±0.08 cm to 4.33±0.12 cm. *P. vulgaris* showed a marked decrease from 34.53±0.12 cm to 25.13±0.09 cm. *Z. mays* and *C. arietinum* also followed this trend, with reductions evident from T0 to T3. The least affected was *C. sativus*, showing a minor decrease from 11.15±0.08 cm to 10.13±0.12 cm (Table 1).
Figure 2: Germination percentage of eight vegetable crops to different concentrations of root exudates of *Chromolaena odorata* at 12 days

<table>
<thead>
<tr>
<th>Treatment</th>
<th><em>A. esculentus</em></th>
<th><em>S. lycopersicum</em></th>
<th><em>P. vulgaris</em></th>
<th><em>Z. mays</em></th>
<th><em>C. arietinum</em></th>
<th><em>C. sativus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>T₀</td>
<td>20.22±0.08</td>
<td>5.42±0.08</td>
<td>34.53±0.12</td>
<td>8.52±0.16</td>
<td>12.4±0.18</td>
<td>11.15±0.08</td>
</tr>
<tr>
<td>T₁</td>
<td>10.42±0.08</td>
<td>4.71±0.08</td>
<td>23.13±0.12</td>
<td>4.17±0.12</td>
<td>9.35±0.08</td>
<td>7.13±0.08</td>
</tr>
<tr>
<td>T₂</td>
<td>12.40±0.08</td>
<td>3.43±0.08</td>
<td>17.13±0.12</td>
<td>8.2±0.08</td>
<td>7.67±0.08</td>
<td>8.21±0.08</td>
</tr>
<tr>
<td>T₃</td>
<td>7.25±0.08</td>
<td>4.33±0.12</td>
<td>25.13±0.09</td>
<td>8.23±0.16</td>
<td>4.24±0.08</td>
<td>10.13±0.12</td>
</tr>
</tbody>
</table>

In table 2, the data showed a general trend of declining root length with the increasing concentration of root exudates. The root length of *A. esculentus* exhibited a decrease from 6.56±0.11 cm in the control to 5.11±0.07 cm at the highest exudate concentration (T3). In *S. lycopersicum*, a similar reduction was observed from 5.44±0.08 cm to 2.45±0.13 cm. The root growth of *P. vulgaris* was also adversely affected, showing a decrement from 13.06±0.09 cm to 6.11±0.07 cm. *Z. mays* and *C. arietinum* demonstrated a decline consistent with the other species. Notably, *C. sativus* presented the least sensitivity to the root exudates, with root lengths mildly reduced from 4.89±0.05 cm to 2.12±0.06 cm.

Table 2: Root Length of eight vegetable crops to different concentrations of root exudates of *Chromolaena odorata* at 12 days (Mean±SEM)

<table>
<thead>
<tr>
<th>Treatment</th>
<th><em>A. esculentus</em></th>
<th><em>S. lycopersicum</em></th>
<th><em>P. vulgaris</em></th>
<th><em>Z. mays</em></th>
<th><em>C. arietinum</em></th>
<th><em>C. sativus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>T₀</td>
<td>6.56±0.11</td>
<td>5.44±0.08</td>
<td>13.06±0.09</td>
<td>14.41±0.09</td>
<td>11.57±0.11</td>
<td>4.89±0.05</td>
</tr>
<tr>
<td>T₁</td>
<td>7.38±0.09</td>
<td>4.17±0.12</td>
<td>11.4±0.08</td>
<td>13.33±0.10</td>
<td>11.17±0.12</td>
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Figure 3: Treatment of aqueous (T1-T3) root exudate extracts of C. odorata on the germination of crop plants (A-F) at 12 days. Where * = p < 0.05, **p < 0.01, *** = p < 0.001, and **** = p < 0.0001 indicates significance levels between the treatments and control (T0). ns = not significant. A (Abelmoschus esculentus), B (Solanum lycopersicum), C. (Phaseolus vulgaris), D (Zea mays), E (Cicer arietinum), F (Cucumis sativus)

Chlorophyll Content in Response to Root Exudates

The experimental analysis presented in figure 3 investigates the impact of extracts from C. odorata root exudates (T1-T3) on chlorophyll levels in six different crop species over a 10-day period. The findings reveal a generally suppressive effect on chlorophyll production across the species, with variations in response. Abelmoschus esculentus showed a significant reduction in chlorophyll levels in response to all treatments, with the effect being statistically significant (p < 0.0001) particularly for T3. Solanum lycopersicum experienced a notable decline in chlorophyll a levels under all three
treatments (T1-T3) \((p < 0.0001)\), whereas chlorophyll b levels were also reduced significantly \((p < 0.01)\), though to a lesser extent; T1 showed no significant impact (ns, \(p > 0.05\)). *Phaseolus vulgaris* displayed a significant inhibition in germination with T2 and T3 treatments \((p < 0.0001)\), while *Zea mays* was distinctly sensitive, with all treatments markedly decreasing chlorophyll contents, exhibiting similar effects for T2 and T3 \((p < 0.0001)\). A similar pattern was observed for chlorophyll content in *Cicer arietinum* with T2 and T3. *Cucumis sativus* experienced a significant decrease in chlorophyll with T2 and T3 \((p < 0.0001)\), whereas T1 led to a less pronounced reduction \((p < 0.01)\). The overarching and dose-dependent inhibitory effect of T3 across all tested species suggested a potent response to the exudates from *C. odorata*.

![Figure 4: Treatment of aqueous (T1-T3) root exudate extracts of *C. odorata* on the MDA contents of crop plants at 12 days (Mean±SEM)](image)

**MDA Content as a Marker of Oxidative Stress**

Research examining oxidative stress across different crop species uncovered distinct responses, as evidenced by malondialdehyde (MDA) measurements (Figure 4). *Abelmoschus esculentus* exhibited a sequential increment in MDA levels from 0.045 \(\mu\text{mol/g.FW}\) in the baseline control (T0) to 0.05, 0.082, and 0.085 \(\mu\text{mol/g.FW}\) across treatments T1 to T3, respectively. Conversely, *Solanum lycopersicum* showed a rise in MDA to 0.065 \(\mu\text{mol/g.FW}\) in T2, then a decline to 0.05 \(\mu\text{mol/g.FW}\) in T3, indicating an adaptive response to stress. *Phaseolus vulgaris*’s MDA levels escalated from 0.025 \(\mu\text{mol/g.FW}\) at T0 to 0.080 \(\mu\text{mol/g.FW}\) by T3. Additionally, *Z. mays*, *Cicer arietinum*, and *Cucumis sativus* all experienced a consistent increase in MDA levels, peaking at 0.085 \(\mu\text{mol/g.FW}\) in T3, pointing to their heightened sensitivity to *C. odorata*-induced stress reflecting diverse antioxidative defense capabilities among the studied species (Figure 4).
Discussion

Root secretions play a pivotal role in how plants interact with their environment, with a variety of allelo-chemicals extracted using methods like water or organic solvent techniques (Bertin, Yang and Weston, 2003; Lou, Davis and Yannarell, 2015; Singh et al., 2021). Weeds stand out for their ability to quickly generate large amounts of biomass and withstand environmental pressures, negatively influencing surrounding plants through both allelopathic effects and direct competition for nutrients and space (Khamare, Chen and Marble, 2022; Kubiak, 2022). The outcomes of this study indicate that the root exudates of C. odorata have substantial allelopathic impacts, significantly influencing the germination processes of six different crop species. Variability in the effects of these exudates was observed, contingent upon the specific plant species under consideration and the concentration levels of the exudates applied (Figure 2). The initial germination inhibition observed in Abelmoschus esculentus, Solanum lycopersicum, and Cicer arietinum underlines the potent allelopathic influence of C. odorata. These findings are in concordance with previous studies that have documented the inhibitory effects of allelo-chemicals on seed germination and plant growth (Krumsri, Kato-Noguchi and Poonpaiboonpipat, 2020; Poonpaiboonpipat, Krumsri and Kato-Noguchi, 2021; Sisodia and Siddiqui, 2010; Xuan et al., 2004).

Notably, the partial recovery in germination rates in subsequent treatments may indicate an adaptive mechanism (Raza et al., 2022) or reduced sensitivity to lower concentrations of exudates, suggesting a distinction interaction between plant species and allelo-chemicals (Liu et al., 2021; Sahid and Yusoff, 2014; Se, Se and Se, 2023; Shaolin, Wen and Qin-Feng, 2004).

P. vulgaris displayed a moderate but consistent decline in germination, which aligns with the theory that certain species possess inherent tolerance levels to allelo-chemicals (Hickman et al., 2020; Reigosa, Pedrol and González, 2006). This tolerance can be attributed to the activation of detoxification pathways or the alteration of membrane permeability to mitigate the effects of allelo-chemicals (Bakhshayeshan-Agdam and Salehi-Lisar, 2020; Shabala, 2010). Zea mays exhibited a non-linear response, with a significant drop in germination followed by a slight recovery. This pattern may reflect a threshold effect where germination inhibition occurs up to a certain concentration of allelo-chemicals, beyond which the effect plateaus or diminishes (Em, 2017). C. sativus emerged as the least affected species, maintaining high germination rates throughout the treatments. This resilience could be advantageous for intercropping systems, where C. sativus could be paired with crops susceptible to C. odorata’s allelopathic effects to mitigate overall yield losses (Zhang, Yan and Wu, 2022). Inhibition of C. sativus when co-cultivated with neighboring plant species, such as Eruca sativa suggested a species-specific manner (Sahid and Yusoff, 2014).

Assessing plant shoot and root lengths is crucial for understanding weed-crop competition. Typically, increased weed competition leads to reduced shoot and root lengths in crops. However, it’s not just competition that poses a threat; the allelopathic effects of weeds are particularly concerning for crop growth. This study focused on how root exudates from different weeds affect the shoot lengths of crop species (Table 1 and 2). This supports previous research indicating that root exudates hinder both shoot and root growth due to the presence of harmful substances (El-Halmouch, Benharrat and Thalouarn, 2006; Sun et al., 2022). The findings of this study echo
earlier studies, suggesting that the detrimental effects on crop seedlings result from weed allelopathic residues, rather than nutrient scarcity. Specifically, water-soluble phenolic acids released by weeds are identified as key inhibitors. Channappagoudar and Agasimani (2003) emphasized the role of phenolic compounds as significant phytotoxins, crucially hindering the early growth stages of seedlings (El-Halmouch, Benharrat and Thalouarn, 2006; Guangdong, Zhang and Cheng, 2009). However, C. sativus demonstrated resilience with marginal reduction in shoot and root lengths. These findings align with previous studies illustrating plant-specific responses to allelopathic substances (Bais et al., 2003; Saleh and Madany, 2004; Tokarz et al., 2020). The inhibition of seedling growth in the target species echoes earlier studies on the growth of some ornamental plants (Zhang, 2008) and vegetable crops (Cheng and Peng, 2013). Results of this study are consistent with existing literature indicating that the inhibitory effect is influenced by the concentration of the extract (Guo et al., 2010; Yasumoto et al., 2011). Zhang et al. (2012) found F. bidentis residues to adversely affect the early growth of cotton and impact soil fertility by releasing water-soluble allelochemicals. Root secretion is its main allelochemical release pathway (Fen, Tao and Pang, 2009), which mainly includes flavonoids, thiophenes, phenolics, esters and steroids (Li, Hou and He, 2014; Sun et al., 2022). Moreover, Lei et al. (2010) reported that the allelopathic effects of ginseng root exudates on the seed germination of four medicinal plants were concentration and receptor dependent.

The experimental analysis demonstrates a consistent suppressive impact of C. odorata root exudates on chlorophyll levels across various crop species in response to treatments T1-T3 over a 10-day period (Figure 3). Notably, A. esculentus and S. lycopersicum experienced significant reductions in chlorophyll levels across all treatments, with some variations in the extent of suppression among the species. This broad-spectrum inhibitory effect, especially pronounced with treatment T3, suggests a potent response to C. odorata root exudates (Figure 3) aligning with previous studies conducted by Taïbi et al. (2016) on P. vulgaris L. This decrease in chlorophyll content is indicative of oxidative stress, a common response observed in various crops (Aazami, Rasouli and Ebrahimzadeh, 2021). The decline in chlorophyll levels can be attributed to the inhibition of chlorophyll synthesis and the activation of chlorophyll degradation facilitated by chlorophyllase enzymes (Kuai, Chen and Hörtensteiner, 2017). Whether through impeding synthesis or accelerating breakdown, the reduction in chlorophyll content suggests a photo-protection mechanism aimed at diminishing light absorbance (Harpaz-Saad, 2007; Zhao et al., 2020). The research conducted by Scavo and Mauromicale (2021) brings attention to the potential resilience of crops in the face of allelopathic stress, as indicated by the lack of malondialdehyde (MDA) accumulation despite the reductions in chlorophyll levels. This finding suggests that certain crop genotypes possess inherent mechanisms for mitigating the physiological impacts of allelochemical exposure (Álvarez et al., 2023).

The increase in MDA content across different treatments and species suggests oxidative stress as a result of the root exudate exposure (Figure 4). Previous research has identified MDA as a biomarker for lipid peroxidation, which is a consequence of oxidative damage (Xu et al., 2022). The escalating MDA levels from T0 to T3 align with findings of Jaballah, Zribi and Haouala (2017) who revealed that chickpea aqueous extracts induce a significant increase in MDA levels in the Nsir lentil variety, indicating enhanced oxidative stress. Huang et al. (2017) observed a similar response
in *Z. matrella* exposed to *A. philoxeroides* subjected to allelopathic stress. In this study, *Z. mays* and *C. arietinum* suggest a common oxidative stress, which is corroborated with Motmainna et al. (2021) who found the same in *Ageratum conyzoides* L., *Oryza sativa* f. spontanea (weedy rice) and *Cyperus iria* L. in glasshouse condition when treated with *Parthenium hysterophorus* extract. The variance in the sensitivity among different species, as observed in *C. sativus* showing elevated MDA (malondialdehyde) levels, may be ascribed to distinctive antioxidant defense mechanisms unique to each species. It has been supported by the work of Hasanuzzaman, Nahar and Fujita (2013). Moreover, the unique response of *Solanum lycopersicum*, which exhibited an initial increase followed by a decrease in MDA levels in T3, might be indication of an adaptive antioxidative strategy. This pattern mirrors the observations made by Yang et al. (2024), who reported a similar adaptive response in *Camellia oleifera* under drought stress. The variance in stress responses among the species studied could also reflect genetic differences in antioxidative defense pathways. As noted by Sarkar and Oba (2020), genetic variability plays a significant role in determining the efficiency of enzymatic and non-enzymatic antioxidative defenses, which could explain the differential responses observed in this study. Furthermore, the heightened sensitivity of certain species to stress from *C. odorata* gives emphasis to the understanding interspecies interactions and their impact on antioxidative defenses. Studies such as those by Silva et al. (2018) highlight the ecological and biochemical complexities of plant-plant interactions under stress conditions, which could offer insights into the varied responses observed in this research.

The extraction method employed to isolate specific compounds plays a crucial role in understanding the mechanisms behind allelopathy. It facilitates the identification of the compounds that contribute to the chemical interactions of *C. odorata* with its environment, highlighting its competitive edge over other flora (Poonpaiboonpipat, Krumsi and Kato-Noguchi, 2021). In this study, a water extraction method is used, which is a common approach in this field. For instance, Mason-Sedun, Jessop and Lovett (1986) noted a pronounced inhibitory effect of water extracts from *Brassica nigra* on wheat growth, while Oleszek (1987) found that volatiles from *B. nigra* suppressed germination in lettuce, barnyard grass, and wheat. Brown and Morra (1996) proposed that such inhibition might stem from the enzymatic breakdown of certain compounds, which release substances that block germination. In a similar vein, Alsherif et al. (2013) observed that water extracts and root exudates from black mustard significantly hindered the germination and growth of *Trifolium alexandrinum*, *Triticum aestivum*, *Phalaris paradoxa*, and *Sisymbrium irio*, noting a concentration-dependent effect where higher concentrations of aqueous extracts completely halted germination in all studied species. This finding corroborates the results of investigation under this study. Current findings align with theories proposing that the allelopathic influence of *C. odorata* results from the collective action of multiple compounds, rather than a solitary substance (Poonpaiboonpipat, Krumsi and Kato-Noguchi, 2021). This collaborative effect might generate new inhibitory agents or intensify the phytotoxic properties of existing molecules. Understanding these dynamics aids in elucidating plant-plant interactions and optimizing crop management strategies (Beck, Kleiner and Garrell, 2022).
Conclusion

In conclusion, the study elucidates the substantial allelopathic impacts of *Chromolaena odorata* root exudates on the germination and growth of six crop species unveiling the intricate and varied responses among different crops, underlying the complexity of allelopathic interactions in agricultural settings. The differential sensitivity observed among the species concentrates the potentiality for utilizing allelopathy as a strategic tool in sustainable weed management, though it also highlights the necessity for a distinct understanding of these interactions to avoid detrimental effects on crop health. The findings reveal a spectrum of responses from substantial inhibition to slight or partial recovery in germination rates across species, indicating the presence of specific metabolic or adaptive mechanisms to counteract allelopathic stress. The pronounced reductions in shoot and root lengths, alongside the significant decrease in chlorophyll content and increase in malondialdehyde levels, further emphasize the potential stress and damage induced by the allelo-chemicals present in *C. odorata* exudates. This research contributes to the growing body of knowledge on the ecological roles and impacts of allelopathy in agriculture, suggesting the necessity for further detailed studies to isolate and identify the active compounds within *C. odorata* exudates. Understanding these allelo-chemicals and their modes of action could lead to the development of novel, eco-friendly weed management strategies that leverage the natural inhibitory effects of certain plant species while safeguarding crop health and productivity. The possibility of using allelopathy as a sustainable substitute for conventional herbicide approaches in weed management is evident. However, its effective implementation demands a careful balance to harness its benefits without inadvertently harming desired crop species.

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Kraehmer, H., Laber, B., Rosinger, C., and Schulz, A. (2014). Herbicides as weed control agents: state of the art: I. Weed control research and safener technology:


Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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Research Involving Local Community Participants (Non-Indigenous) or Children

The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

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To see original copy of these declarations signed by Corresponding/First Author (on behalf of other co-authors too), please download associated zip folder [Declarations] from the published Abstract page accessible through and linked with the DOI: https://doi.org/10.33002/nr2581.6853.070101.
Incorporating Islamic Environmentalism in Approaches to Conservation in the Trans-Himalaya

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Abstract

Conservationists increasingly acknowledge the value of co-productive conservation efforts that incorporate the Indigenous perspective. In the Trans-Himalayan context, they have begun to incorporate the Buddhist perspective in recent interventions; yet, there is an omission of Islamic environmentalism in these conversations. This omission is even more glaring when one considers that Muslims make up a significant percentage of the Indigenous population of the Trans-Himalaya. A review of the literature reveals a considerable body of Islamic scholarship on sustainable resource management in extremely harsh climates. In fact, co-productive conservation efforts in collaboration with local Muslim communities elsewhere in the world have been very impactful. While scholarship on the history of Islam in the Trans-Himalaya is limited, historians agree that, rather than being forced upon a passive Indigenous population, the widespread adoption of Islam was an active choice by a population that had plenty of exposure to different ideas and belief systems via trade. Supplementing these findings with qualitative research at the grassroots level among the Dard-Shin Scheduled Tribe in the Trans-Himalaya, the authors find further evidence of the syncretic blending of Indigenous and Islamic beliefs, deployed in service of effective natural resource management. It is, thus, proposed that future conservation efforts in this region would be well advised to adopt a more expansive approach to the Indigenous perspective.

Keywords

Islam; Trans-Himalaya; Conservation; Indigenous; Co-productive conservation; Scheduled Tribes

Introduction

For several decades, conservation scientists have acknowledged the importance of participation of Indigenous communities in conservation. Nonetheless, “Indigenous” is often a term of art, and who gets to be construed as such depends on external political factors. The authors’ work in the Trans-Himalayan region of Kargil,
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Ladakh, focuses on the documentation of native medicinal plant species and the improvement of rural livelihoods via agroecological intervention. During this process, the authors have discerned a troubling erasure of Muslim communities and traditions within the larger conversation around conservation in the Himalayas, which appears to be based on the assumption that one cannot be both Muslim and indigenous to the region. It is important to recognize that although such communities are officially classified by the Indian government as belonging to Scheduled Tribes, Islam is their primary organizing principle. Islamic teachings on living harmoniously with nature in a resource-scarce region, combined with the traditional knowledge of their ancestors, have played an important role in enabling Ladakhi Muslims to thrive in the harsh environment. Thus, the ever-evolving practice of Islam in the Trans-Himalaya has the potential to be an effective tool in resource management in an area at the forefront of climate change, and conservation practitioners ignore it at their peril.

A conclusion is arrived at based on a review of the literature, the authors’ observations in the region, the authors’ experiences working with communities at the grassroots level, and the well-documented evidence on how improving communication with key local stakeholders increases likelihood of success in a conservation intervention. Although the terms “Trans-Himalaya” and “Ladakh” are deployed to emphasize the applicability of the thesis to a larger geography, the focus is primarily on Kargil, as this is the region where the authors have conducted their research.

Co-Productive Conservation

For too long now in the Trans-Himalaya, there have been multiple instances of impressive conservation policies that fail to translate into the anticipated-for impact on the ground. Those who study such failures generally attribute them to an inadequate consideration of the social aspects of conservation (Bennett et al., 2017). Conservation is “primarily not about biology, but people and the choices they make” (Balmford and Cowling, 2006; Wright, 2015). Given the people-centric nature of conservation, Catalano et al. (2019) identify poor communication as one of the primary causes of policy failure. Toomey, Knight and Barlow (2016) go a step further and argue that the research-implementation gap can only be bridged when scientists acknowledge that, though we live in the information age, human decision making is as much influenced by objective science-based evidence as it is (if not more so) by existing beliefs and mental models. “Effective decision-making,” they write, “is based upon clear understandings of values, knowledge, rules, behaviours and actions, and the complex interactions between them” (Toomey, Knight and Barlow, 2016). The extent to which the local cultural context is acknowledged and given recognition during the process of research can have a significant impact on the degree to which the findings of that research are accepted by the local community.

For example, in Muslim-majority Zanzibar, the Islamic Foundation for Ecology and Environmental Sciences, headed by the Islamic environmentalist Fazlun Khalid, developed and implemented an Islam orientated environmental education programme amongst the fishing communities with great effect (Khalid and Thani, undated). Elsewhere within the Islamic world, the issuance of fatwas (prohibitions) has also been

1 https://www.constitutionofindia.net/articles/article-342-scheduled-tribes-2/
able to put a stop to polluting practices where government regulation has failed (Schwencke, Berger and Drees, 2015).

In response to the need for both science- and community-based understandings of environmental issues and the solutions thereof, Buschman (2022) advocates for co-productive conservation, i.e. the co-production of knowledge and public services, which means to produce ethically conscious, culturally relevant and fully knowledge-based approaches to biodiversity conservation. This approach, she further elaborates, “must be equitable and meaningful and in line with Indigenous sovereignty and self-determination; must be open to traditional methods of management and conservation as guided by Indigenous knowledge and ways of life and must not unnecessarily impede traditional practices; and must trust and respect Indigenous knowledge, its methodologies, and its validation and evaluation processes as legitimate and take Indigenous direction on how Indigenous knowledge and science should be partnered in the creation of a shared evidence base.” Buschman (2022), like Toomey, Knight and Barlow (2016), emphasizes that Indigenous participation in conservation should not be an obligation; instead, there should be a recognition by scientists that broadening the evidence base to include Indigenous knowledge will increase the likelihood of success.

In Buschman (2022)’s envisioning, co-productive conservation entails six processes:
1. Co-planning, or bringing indigenous partners on at the planning and conceptualization phase;
2. Co-prioritizing, or setting the agenda together with indigenous partners;
3. Co-learning, or synthesizing the information together in a way that is both science and traditional knowledge based;
4. Co-managing, or the collective allocation of resources for the project;
5. Co-delivering, or jointly conducting researching as well as establishing community-based monitoring; and lastly,
6. Co-assessing, or conducting a joint evaluation of whether the project met its objectives.

Matters get a bit more complex in the Indian context (Xaxa, 1999). “Indigenous” is not mentioned in the Indian constitution, as the government considers all Indians to be indigenous to the country. It is also for this reason that “Indigenous” is not capitalized in much of the Indian literature, in a break with standard practice in North America.2 The nearest Indian equivalent to the North American term is “Scheduled Tribe”, which is defined in an almost comically circular manner in Article 342 (1) of the Constitution3 as “the tribes or the tribal communities or parts of or groups within tribes or tribal communities, after the consultation with the Governor thereof, which the President may specify by public notification.” In other words, a Scheduled Tribe is one that the government deems as such.

Thankfully, over time the government and courts have shed a little more light on which groups may be classified as Scheduled Tribes. Typically, they live apart in the mountains, lead an excluded life and are not fully assimilated into the mainstream. They may belong to any religion (Bodhi and Darokar, 2023). Possibly because of

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3 https://constitutionofindia.in/article-342-of-indian-constitution/
overlapping characteristics, and as the practice of conservation has become more globalized, terms that are more suited to a particular context elsewhere gradually snake their way into popular parlance within India. Thus, it has come to pass that practitioners often use “Indigenous” interchangeably with “Scheduled Tribes” in India. It should also be noted that the rights conferred by a Scheduled Tribe designation are discretionary, with some tribal areas getting far more autonomy than others.

Notably, over 80% of the population of Kargil, Ladakh identify themselves as belonging to a Scheduled Tribe (though they have been granted relatively limited autonomy over their area). In an overlap of identities, 76.9% of these Kargilis also identify themselves as Muslims. It stands to reason then that a significant majority of Kargil’s population is both Muslim and tribal/Indigenous. And, when one takes into consideration all Ladakh, according to the 2011 census, Muslims make up 46.6% of the population, with Buddhists at 39.7% and Hindus at 12.1%. Regardless of demographic realities, the image most frequently conjured upon mention of the Indigenous communities of the Himalayas is that of the crimson-clad Buddhist monk against a stark white landscape, thanks in no small part to Hollywood films like *Seven Years in Tibet* and *Kundun*. One might speculate that the visual appeal of such imagery is the primary reason for its popularity with filmmakers. Nonetheless, it erases from public consciousness a very significant group of non-Buddhist Indigenous Himalayan dwellers: its Muslim population.

This erasure extends beyond movie theatres to academia, whether in Islamic or environmental studies department, where it is uncritically held that the geography of Islam is limited to the desert ecologies of the Middle East, and “that Muslims are outsiders to the Himalaya, and that the Himalaya are a peripheral site of Muslim cultures and traditions” (Fewekes and Sijapati, 2021). And yet surely Islam, with its origins in a resource scarce region like the Arabian Peninsula, would be especially concerned with the sustainable and just distribution of scarce resources. Without taking away anything from Buddhism's contribution to an ecologically conscious way of life in the Himalayas, let it be noted that Buddhism is no less “foreign” to this region, having originated in the much warmer subtropical foothills. Research in Ladakh by Bhatia et al. (2016) shows that professing the Buddhist faith does not predispose one more favourably towards the environment any more than professing the Islamic faith. The historian Richard C. Foltz (2003) takes a critical look at Islam’s claims to being an eco-religion. He suggests that contemporary Muslim writers on the issue are more concerned with environmentalism as a social justice issue than for its own sake. But if one could point to a single reason for Islam’s invisibility in modern environmental discourse, it would be the poor environmental records of the two modern-day oil-producing theocracies in the Middle East, namely Iran and Saudi Arabia. Witness, even as Dubai hosts the latest round of UNCCCF’s COP 28 talks, the steady flow of articles

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in the Western press that are almost incredulous that an Arab country could be
entrusted with any kind of environmental stewardship.\(^6\)

The ecotheologian Mawil Izzi Dien (2003) describes the environmental catastrophe in
Saudi Arabia, more closely identified than any other place with a “pure” Islam. In the
wake of oil discovery, Saudi agriculture, itself a miracle, collapsed. As a result, many
species of flora and fauna, which had come to depend on centuries-old agricultural
introduction of the industrial age to these countries was not supported by a value
system compatible with the prevalent Islamic values.” He posits that this led to a
values vacuum, which people attempted to fill with ever-increasing over-consumption.
It was not uncommon in those days to find abandoned cars by the side of the road,
barely a few years old, as their former owners moved on to the next shiny new thing.

It is widely held that the Syrian war was the first climate war of our time, following
the path of drought-migration-conflict (Angermayr, Dinc and Eklund, 2023). The shadow
of that war falls on Iran’s current environmental crisis. In 2020, the country saw a
series of protests over water shortages in Khuzestan, a region that used to be water
rich. The water crisis is exacerbated by decades of resource mismanagement. Iran also
has very high levels of air pollution because of the widespread use of poorly refined oil
and outdated emission technology. As a result of environmental decline in agricultural
areas, the pace of rural-urban migration has increased in recent years.\(^7\) The country
now has a large and restive under-employed youth population, whom many blame for
the anti-regime protests in 2023.\(^8\)

Still, the careful scholar should distinguish between Muslim environmentalism and
Islamic environmentalism, as Foltz (2003) reminds us. The Iranian and Saudi response
to the curse and blessing of oil are examples of Muslim environmentalism, which is
not, however, the same thing as Islamic environmentalism. The latter originates in the
writings of the Qur’an, while the former is practiced by discrete groups of Muslims and
is very much shaped by local conditions. The shortcomings of one should not be
conflated with the other.

Within the Indian subcontinent, a key point of difference between Islamic and Hindu-
Buddhist environmental traditions has to do with vegetarianism. While Hinduism/Buddhism is widely known for preaching ahimsa or non-violence, this is not
the case with Islam. Islamic celebrations such as Bakr-id, which entails the slaughter of
goats, tend to contribute to the perception that environmental consciousness does not
top the list of Islamic concerns.


On closer inspection, there is plenty of non-vegetarianism within Hindu India, as well as in Buddhist culture throughout East and Southeast Asia. Moreover, on the Tibetan plateau, where the ground is frozen solid for at least six months in a year, historically meat has played a crucial role in providing basic nourishment for all residents, regardless of religious affiliations. Simultaneously, there is nothing in Islam that prohibits vegetarianism. Nonetheless, since the tendency is always to define oneself against the other, Islam in India becomes the non-vegetarian alternative to vegetarian Hinduism. It becomes concerned with distributive justice among the disenfranchised, rather than with upper caste “luxury concerns” such as environmentalism.

**Key Concepts in Islamic Environmentalism**

Before jumping into the particularities of Muslim environmentalism in Kargil, it would be helpful for the non-Muslim readers to gain familiarity with relevant principles of Islamic environmentalism. To understand again why this might be necessary, one must revisit the words of James Gustave Speth, former dean of the School of Forestry & Environmental Studies at Yale University and senior advisor on environmental issues to US presidents Carter and Clinton, who has been widely attributed to say: “I used to think the top environmental problems were biodiversity loss, ecosystem collapse, and climate change. But I was wrong. The top environmental problems are selfishness, greed, and apathy” (Sterling, 2019). Speth went on to say that “to deal with those issues we need a spiritual and cultural transformation – and we scientists do not know how to do that”.

Speaking for religion, the Islamic philosopher of science, Sayyed Hossein Nasr (2000), writes that religious perspective illuminates a profound interconnection between humans and the natural world, emphasizing adherence to a shared universal order. He urges contemporary individuals to embrace traditional religious perspectives on nature and align their actions with the natural order, mirroring the harmony observed by other beings: “We must realize that the traditional religious wisdom applies to us as much as it did to our remote ancestors, and that humanity must be seen, as it once was, as an inseparable part of the natural world, as God’s creation and subject to the same divinely ordained laws that must be observed if we are to maintain its fundamental order” (Nasr, 2000).

**Āyāt**

The transcendent and spiritual reality of nature is a key tenet of Islamic environmentalism. Everything in nature is seen as a sign of God (Āyāt). Because nature cannot explain its reason for being, its existence points to some transcendental entity. In the Islamic view, nature consists of the attributes of God, and the purpose of the cosmos is to make him known (Ma’rifa). Muslims believe that everything in the natural world is a manifestation of God's creation. Just as footprints indicate someone's presence, the existence of nature serves as evidence of God's existence. The belief in Allah as the Creator of all things is a fundamental concept, as emphasized in the Qur'an, which is the...

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holy book of Islam. Surah Al-Hashr (59:24)\textsuperscript{10} specifically mentions that Allah is the Creator, the initiator, and the supreme fashioner. This concept is reinforced in other verses throughout the Qur’an. In Surah Al-An’am (6:102)\textsuperscript{11}, it is stated that Allah is the Creator of the heavens and the earth. In Surah Al-Rad (13:16)\textsuperscript{12}, it is mentioned that Allah is the best of Creators. These verses, along with many others, highlight the role of Allah as the sole Creator and guardian of all things.

Do they not realize that Allah, Who created the heavens and the earth and did not tire in creating them, is able to give life to the dead? Yes, He is certainly Most Capable of everything (Qur’an: Surah Al-Isra. 17:99).\textsuperscript{13} In fact, nature is one of the two Āyāt of God, the other being the Qur’an itself. The Qur’an is a revelation from God to humankind, and it serves as a written form of God's words. It provides guidance to Muslims and offers profound insights into the relationship between Allah, the heavens, the Earth, and the human beings as his creation. The Āyāt of the Qur’an emphasize the intricate design and balance (Mizan) in cosmos and nature, indicating that everything in the universe along with the earth and environment is a creation of God. “It is a revelation from the One Who created the earth and the high heavens” (Qur’an: Surah Al-Taha. 20:4).\textsuperscript{14}

The historian S. Nomanul Haq (2001) writes, “Nature in its Qur’anic conception is anchored in the divine, both metaphysically and morally. The expression is strong: ‘But to God belongs all things in the heavens and on the earth; and He is who encompasseth (Muhit) all things (4:126)’; note that the word Muhit can also be translated legitimately as ‘environment’. So we see that when the Qur’an’s notion of nature is reconstructed in the larger framework of this supreme Islamic source, it appears inherently connected with its notions of God and humanity — and all these notions, as we have seen, have their roots in the transcendental realm…”

An important distinction to note, however, especially in the context of other animist traditions in the Himalayas, is that in Islam, nature is not worshiped, though it holds great importance as a sign of God’s existence. The Qur’an teaches that “Allah is glorified by all those in the heavens and the earth” (Qur’an: Surah An-Nur 24:41).\textsuperscript{15} Being surrounded by nature is seen as a source of peace and tranquility, as it reminds individuals of God's presence and brings a sense of pleasure to the mind and heart. Overall, nature is highly valued in Islam as a sign of God’s existence and a means of finding peace and connection with the divine.

**Tawhīd**

Another key tenet is Tawhīd or the interrelatedness of all things. The ecological sensitivity in Islam is grounded not in anthropocentrism or biocentrism but is predicated on the unity of all things. Dien (2003) further translates this to mean that there is no reality outside of the Absolute Reality, and there can be no scientific or
intellectual effort that exists apart from the Absolute Reality. According to the wisdom of the Sufi poet Rumi (as cited in Clarke, 2003), Tawhīd is a holistic understanding of nature as “a system and process, with an overall meaning and end in which all parts have their place, without exception — whether they might be considered from a more limited point of view beneficial or deleterious, good or evil. The vision desired is, in a word, ecological — an ecology that includes not only biology and physics, but also metaphysics.”

For the aspiring co-productive conservationist, it is instructive to contrast Tawhīd with the modern science of ecology, in which one encounters the technical term homeostasis, which means, in the tradition of mechanical engineering, a self-regulatory feedback mechanism. As long as ecology can be seen as a mechanical system, it can be conceived as something that can be managed scientifically, and like a machine it performs function but has no ultimate purpose. And the task for the modern environmentalist is to figure out how much damage an ecosystem can take and maintain that balance at “the edge of the abyss” by technological manipulation without challenging the growth orthodoxy on which capitalism rests (Quadir, 2013).

The authors’ observation at the grassroots level in Kargil reveal that divergent perspectives on growth are perhaps the biggest sticking point: while desirous of a better standard of living, many local people nonetheless reveal a deep-rooted ambivalence about growth and its environmental costs. There is still much reverence for the older, more harmonious way of life predicated on Tawhīd, which provided adequately while leaving a minimal ecological footprint.

**Khalifa**

One of the more controversial concepts in Islamic environmentalism is that of Khalifa or custodianship. The Qur’an says God has placed man as his vice-regent on earth, which begs the question of the nature of this vice regency: is it dominion, or is it trusteeship? “Lo! I am about to place a vice regent on earth” (Qur’an: Surah Al-Baqara. 2:30). Those who interpret it as dominion see in Khalifa parallels to Christianity, which also gives mankind dominion, and which has been interpreted as giving carte blanche to exploit nature for humanity’s ends. To this school of thought belong the Salafists, who, upon Islam’s initial encounters with modernity, saw an urgent need for technological progress to catch up with the western world. In order to elide the more troubling questions raised by the quest for parity, Salafists put modern science squarely within the Islamic tradition.

But according to Nasr (2000), Islamic science is about Tawhīd or unity of being, whilst modern science is about Takhdīr or fragmentation, and, therefore, there is a fundamental difference between the two. It is the former interpretation of the Islamic scientific tradition that also sees Khalifa as meaning ‘trusteeship’. In the Sufi tradition, understanding Allah as the Creator helps Muslims acknowledge His sovereignty and authority over all aspects of life. It also fosters a sense of gratitude and awe. The Qur’an strictly commands human beings not to destroy the Earth, highlighting the

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16 A mystic body of religious practice found within Islam.

17 https://myislam.org/surah-baqarah/ayat-30/
importance of preserving and protecting the environment, as it contains the signs of God's presence and should be treated with reverence. This understanding encourages human beings to appreciate and respect the natural world, recognizing it as a manifestation of God's power and wisdom. “We did not create the heavens and the earth and everything in between for sport” (Qur’an: Surah Ad-Dukhan. 44:38).18

By reflecting upon the beauty and harmony of nature, individuals are encouraged to develop a deeper connection with their Creator. Furthermore, the Qur’an exhorts human beings to be humble and not wasteful. It reminds human beings that they will be held responsible for their actions, including how they interact with the environment. “And do not walk on the earth arrogantly. Surely you can neither crack the earth nor stretch to the height of the mountains” (Qur’an: Surah Al-Isra. 17:37).19 As a result of the primordial covenant between God, Adam and Eve in the Qur’an, human beings are bound to follow God’s commands. Humanity, created in God’s image, is theomorphic. But this comes with a moral burden that “lies not in its [humans] enjoying any higher power or control or authority among created beings; it lies rather in the fact that it is accountable before God, such as no other creature is” (Haq, 2001).

In summary, the Qur’an teaches that human beings have been appointed as custodians (Khalifa) of the natural world by God, and He had sent forth various messengers (Rasul) to carry this message. This responsibility stems from a covenant made in pre-eternity (Mithaq), where humans acknowledged their divine nature and committed to preserving the balance (Mizan) and order in the cosmos. This commitment to maintaining due measure (Qadr) towards God is considered the primary moral duty of humanity. “As for the earth, We spread it out and placed upon it firm mountains, and caused everything to grow there in perfect balance” (Qur’an: Surah Al-Hijr. 15:19).20

**Sharia**

Sharia (way) is a guide derived from the Qur’an and Sunnah (prophetic tradition), from the Hadith (authentic sayings) of Prophet Mohammad, through the Isnad (chain of narration) of those sayings, bound by the authenticity of those sayings. The conservation of nature within Sharia is not just a recommendation but a duty. This is evident in several Qur’anic verses and Hadiths that discourage wastefulness (Israf). For example, the Qur’an states that waste is an action of Satan (Qur’an: Surah Al-Isra. 17:27),21 and a Hadith narrates that the Prophet Muhammad said, “Do not waste water, even if you perform your ablution on the banks of an abundantly flowing river” (Ibn Majah, Vol. 1, Book 1, Hadith 425).22 These teachings promote a sustainable and balanced approach to using natural resources, emphasizing moderation and efficiency.

Furthermore, Sharia includes specific regulations regarding the use of land, water, and air, as well as the treatment of animals. It prohibits the pollution of water sources, the cutting down of trees without just cause, and cruelty to animals, among other environmentally harmful actions. The concept of "Hima," a protected area for

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18 https://myislam.org/surah-dukkhan/ayat-38/
19 https://myislam.org/surah-isra/ayat-37/
20 https://myislam.org/surah-al-hijr/ayat-19/
21 https://myislam.org/surah-isra/ayat-27/
22 https://sunnah.com/ibnmajah:425
conservation and sustainable use, is an example of an early Islamic environmental practice. Sharia also encourages the preservation of biodiversity and balance (Mizan) among all living things, as mentioned in the Qur’an (Surah Ar-Rahman. 55:7-9). This balance is essential for the well-being of the planet and is a trust that Muslims are expected to uphold.

The History of Islam in Ladakh

Having laid out the bare bones of Islamic environmental philosophy, it would be helpful to understand the channels through which these ideas made their way to the Ladakhi context. As one can see in this section, the incursion of Islam was, for the large part, peaceful, and conversions were mostly voluntary. This begs the question of what the convert felt Islam could offer him or her, particularly in a land where the struggle for survival was far more intense than in the salubrious environment of the rest of the Indian subcontinent. And, if an Indigenous person voluntarily opts for and adapts foreign ideas to meet his/her needs, must those ideas forever be considered foreign? (It would also be worthwhile, at this juncture, to echo the sentiments of the authors of Muslim Communities and Cultures of the Himalayas to wonder why, when discussing a minority group, the impulse is always to account for and justify their existence) (Fewekes and Sijapati, 2021).

There is no master narrative of the emergence of Islam within the Himalayan region, though Muslims have a long presence in the region, dating back to at least the 10th century. Within Ladakh, the story of Islam is an especially layered and complex narrative, with cultural influences from Baltistan, Turkistan, Kashmir, Tibet and Persia shaping Islamic life in the region. In a porous and frequently acausal border region, there is no single school of Islamic thought easily matched against a single ethnic group. Instead, the history reads like a palimpsest, with multiple overlapping stories, from which one may discern an intelligible narrative only with great difficulty. Nonetheless, an effort was made in the mid-1990s by the social anthropologist Pascale Dollfus (1995), and it is from her work that we present the following history. The first mosque in the region was built in Srinagar at the site of a Buddhist temple by Rincana Bhotta, the son of a Tibetan chief, who converted to Islam in 1320 C.E. In the centuries that followed, Turkish invaders from the regions surrounding Ladakh, be it Kashmir or Kashgar, made multiple forays into the wealthy kingdom, often with success, yet always of a temporary nature. Islam gained a more lasting foothold in Purig, the ancient name for Kargil, then a region abutting the Ladakhi kingdom, with the 1405 C.E. invasion of Sultan Sikander Shah of Kashmir.

At the end of the 16th century, Kashmir was conquered by the Mughals, bringing the mighty empire to the doorstep of Ladakh. At the beginning of the 17th century, the king of Ladakh made an alliance with the Muslim chief of Skardu in neighbouring Baltistan, who offered his daughter in marriage on the condition that the king convert to Islam and that the son born of this marriage be the sole heir to the throne. The Balti princess, Rgyal Khatun, brought with her many Shia clerics, including Mir Syed Ali Hamdani, whom Ladakhi tradition credits with building the first Shia mosque in Shrey, the former capital. (According to John Bray (2013), scholarship by Wolfgang 23

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23 https://myislam.org/surah-ar-rahman/
Holzwarth challenges this narrative by crediting the Nurbakshi Shams ud-Din Iraqi with making the first converts in the region. Rgyal Khatun is particularly revered in Shia-majority Kargil, where many descendants of her retinue eventually settled. The king also invited prominent Kashmiri merchants to settle in Ladakh. The son born of this union, Raja Senge Namgyal, himself a devout Buddhist, is revered by Ladakhis as their greatest king.

In 1638 C.E., Mughal forces from Kashmir invaded Baltistan, in reprisal for which the Ladakhi king banned Kashmiri traders from his kingdom. The ban on Kashmiri traders imperilled Ladakh’s strategic position as a trading entrepôt, throwing the economy in disarray, and the kingdom went into decline.

In 1679 C.E., a powerful Mongolo-Tibetan army was sent by the Dalai Lama in Lhasa to bring Ladakh back under the Tibetan fold. Unable to repel the army on his own, the Ladakhi king was forced to ask the Mughal governor of Kashmir for assistance. Once more, the king of Ladakh was forced to convert to Islam, and his son was taken hostage in Kashmir. Ladakh was brought under the suzerainty of the Mughal Empire, and Kashmiri traders settled in the region, establishing a chain of trade settlements along the caravan trail between Tibet, Central Asia and Ladakh. According to Dollfus (1995) and Grist (1995), it was through the ensuing proliferation of trade, rather than invasions or forced conversions, that Islam finally found a permanent home in Ladakh.

One of the outcomes of the 1684 peace treaty between Lhasa, Ladakh and the Mughals was the triennial mission from Ladakh to Lhasa known as Lo Phyag, which bore tribute to the Dalai Lama. As a sign of how integral Muslims had become to Ladakhi society, the management of all practicalities of the Lo Phyag were ceded to Muslim traders experienced in the Trans-Himalayan trade (Bray, 2013). Meanwhile, in Purig, where fewer Sunni Kashmiris had settled, the mostly Shia population continued to engage in agriculture. During this era, interreligious unions, resulting in the conversion of Ladakhi women to Islam, continued unimpeded, and mosques were opened throughout the Himalayan kingdom (Dollfus, 1995).

In the era following Indian independence in 1947, Ladakh was cut off first from Baltistan owing to the formation of Pakistan, and then from Tibet and China following the Sino-Indian war. It lost its pre-eminence as a centre of trade, as well as its cosmopolitan nature, as many of its traders relocated elsewhere (Dollfus, 1995). It was administered as part of the state of Jammu & Kashmir, its concerns largely neglected in the face of the larger turmoil in that state. Since 2019, Ladakh has been bifurcated from Jammu and Kashmir and accorded separate status (Pushkarna, 2019). It has two districts, Leh and Kargil. Kargil is Muslim dominated and Leh is Buddhist dominated, though it also has a Muslim population.

The demands of a sustainable agricultural practice in such a harsh region would have required a continued adherence to hard-won traditional ecological knowhow even after conversion. In her study of a Muslim community in the Nubra valley in the Leh district of Ladakh, anthropologist Smriti Srinivas (1995) observed that regardless of divergence in other aspects, both Buddhists and Muslims in the region “work according to a particular agricultural calendar which creates a degree of conjunction between them.” Srinivas (1995) cites an observation made by a missionary in 1887 of a Muslim community in Kargil making offerings to the village deity and an imam practising Sowa Rigpa medicine, normally associated with Buddhism. This sort of syncretism is further evidence of the fuzzy boundaries of indigeneity in Ladakh.
Ladakhi Muslims today must negotiate a fine balancing act between their Ladakhi and Muslim identities, the latter of which, in the Internet age, is more shaped by the ideals of a global ummah or brotherhood than ever before. Nonetheless, the interplay of these multiple cultural influences - tribal, ethnic, religious, modern, Indian etc. - intermediates their relationship with the natural environment in which they live. And while attention has been given to the other aforesaid influences, curiously none has been paid to the influence of modern Islamic environmental thought, which oversight we shall go on to address in the next section.

**Muslim Environmentalism among the Dard-Shin Scheduled Tribe in Kargil**

As an illustrative example of how the Indigenous Peoples or Scheduled Tribes of Ladakh apply Islamic environmental thought in conducting their daily lives, this section focuses on the Dard-Shin tribe of Kargil (also referred to in this article as the Shinas). The Dard-Shins are a semi-pastoralist tribe whose presence in the region between the Karakoram and Western Himalaya has been documented as far back as the 4th century B.C.E. by the Greek historian Herodotus. For this section, the authors are drawing on personal experience, in addition to the limited scholarly literature available. The Dard-Shins hold a profound reverence for nature, considering it not merely as a resource but as something sacred and divine that necessitates protection and preservation. Central to their belief system is the recognition of the interconnectedness between humans and the environment. This worldview transcends the mere material value of nature, recognizing it as an integral part of their spiritual and cultural identity. Consequently, hunting and harming wildlife are regarded as sins, aligning with a broader ethos that reveres all life forms.

The Bon25 religion, prevalent in the region before the arrival of Islam, encompasses elements of animism that acknowledge the spiritual essence residing within nature. This spiritual belief system perceives inherent vitality and consciousness in natural entities, fostering a deep sense of respect and veneration (Vohra, 1982). Interestingly, despite the advent of Islam in the region, these Indigenous beliefs were not eradicated; instead, Islam rationalized these beliefs by incorporating the notion that all beings, including humans, are part of God's creation. This fusion of Indigenous beliefs with Islamic teachings led to a harmonious coexistence between the two, allowing for the preservation of traditional reverence for nature. The amalgamation of these ideologies underscored the idea that stewardship of the environment is a collective responsibility ordained by a higher power. This blend of spiritual wisdom and environmental consciousness emphasizes the need to safeguard nature not merely for utilitarian purposes but as a duty intrinsic to the Shina’s cultural and religious heritage. This holistic perspective continues to inspire a harmonious relationship between the community and the natural world, advocating for the preservation of their sacred landscapes for generations to come.

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Hima

The concept of Hima as a protected area within Islamic theology is deeply intertwined with the historical practices of tribal and pastoral communities, reflecting a profound reverence for the environment and its inhabitants. The Shinas, nestled deep within the intricate landscapes of the Himalayas, embrace the principles of Hima as a core tenet of their cultural heritage. Central to their practices is the sacred commitment to refrain from the indiscriminate cutting of trees and the hunting of revered animals. This cultural ethos is not merely a customary guideline but an embodiment of their deep-rooted connection with the natural world, driven by a profound understanding of the ecological interdependence between humans and their surroundings.

For the Shina community, the sanctity of certain trees, e.g. juniper (*Juniperus communis*) trees, and the protection of specific animals, e.g. ibex (*Capra ibex*), go beyond utilitarian considerations; it embodies a sacred pact with their environment. These trees might hold historical or spiritual significance, serving as markers of communal identity or repositories of traditional wisdom. Similarly, the prohibition against hunting specific animals might stem from myths, folklore, or religious beliefs that confer a revered status upon these creatures. Their ancient religious ethos is deeply intertwined with the natural world, where sanctity is found in elements like trees and wildlife itself.

Water Management

When it comes to water management, it is not much of a leap to understand the appeal of comprehensive Islamic jurisprudence on water management to the Dard-Shins. Although the laws mostly developed in the hot deserts of the Middle East, the cold deserts of the Trans-Himalaya are no less water constrained, and the principles are universal. Within Islamic jurisprudence, water belongs to that group of resources that man holds in common. No legal person may try to own a river or sell or rent its water. Nonetheless, a person or group who applies his/their labour to clear the land or build an irrigation canal, get(s) ownership rights. Still, “this does not prevent other groups from using the land’s natural, unimproved resources”, as water is a scarce resource (Wilkinson, 1990). Foremost among the hierarchy of rights governing water use is the right to quench thirst. So, for example, a nomad passing through a village has a right to slake his thirst at the irrigation canals within that village, as long as that water is still in its pure, unpolluted state and he does not pollute the water or the area immediately around it. For the semi-pastoralist Dard-Shins, who often go up the mountains to graze herds of sheep or cows, the ability to help themselves to water without courting conflict would be appealing.

John C. Wilkinson (1990), a scholar of Islam, writes that Islamic water law, in principle at least, ensures that the powerful do not encroach on “the rights of the smallholder, and that the interests of the latter are taken into account when any major decisions are made.” In a relatively egalitarian society such as that of the Dard-Shins, where for the most part, landholdings are more or less the same across the population, the Islamic framework for water management would have been particularly useful. The traditional canal network of the Dard-Shins (and more generally the Ladakhis), often referred to as Kanat, represents a sophisticated communal water distribution system
and is rooted in a collective sense of responsibility and reciprocity. Through a combination of gravity-fed channels and diversion structures, this ancient system optimizes water utilization while minimizing wastage — a testament to the ingenuity of traditional engineering and resource management practices.

At the core of this canal system lies a communal ethos, where different clan houses collaborate in a rotational manner, each shouldering the responsibility of channelling water to the fields, plants, and trees during specific periods. This rotational approach reflects a meticulous organization and equitable distribution of water resources among the various stakeholders. The villagers also elect a water official to ensure that no field is unirrigated (Agarwal and Narain, 1997). Such a communal undertaking not only ensures fair access to water but also fosters a sense of solidarity and mutual cooperation within the community. The Kanat system is a good example of how a flexible Islamic jurisprudence can be appropriated by an Indigenous population to buttress and legitimate prior practices. It also challenges the image of a passive and isolated Indigenous population subject to the vicissitudes of rapacious outsiders; instead, here we see the Dard-Shins cherry-picking from various sources to take an active role in shaping how they manage the resources available to them.

Suggestions for Incorporating Islamic Environmental Principles

A feature of the Central Sector Scheme on the Conservation, Development and Sustainable Management of Medicinal Plants of the National Medicinal Plants Board of the Ministry of Ayush (Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homeopathy) in India is the delineation of a Medicinal Plants Conservation and Development Area (MPCDA), which aims to facilitate the in-situ conservation of medicinal plants in their natural habitats. The concept of an MPCDA can easily be translated as Hima, and in so doing, it would be exponentially easier to explain its purpose to the Shinas. One can envision a more impactful co-planning and co-productive process where Shina community members show conservationists pre-existing Himas in the area, and conservationists eschew an MPCDA in favour of a Biodiversity Heritage Site (under the Biological Diversity Act, 2002) that is more or less coterminous with those Hima. The process would entail a degree of negotiation, but rather than introducing an entirely new concept in the foreign, secular language of science, why not build on what has come before?

27 Were Community Conserved Areas (CCAs) ever to be accorded legally protected status under Indian law, they could also serve as a more effective model. As Avinashi (2023) of the Kalpavriksh foundation eloquently puts it, “Although, Protected Areas (PA) have been significant in saving certain species from the verge of extinction and protecting ecosystems from mega-development projects due to their legal status, but the inherent assumption concerning the nature of most PAs comes from the colonial notion of conserving biodiversity that separates humans from nature and leaves little to no space for co-existence. Alternatively, CCAs are territories that act as corridors for animal movement and can complement PAs with a focus on landscape management. Additionally, biodiversity conservation is not always a primary objective for communities; however, it is an integral part of their livelihoods or cultural beliefs by virtue of existing systems, which makes CCAs a key entry point in bridging the gap between local livelihoods with conservation. CCAs are also essential in maintaining ecosystem services such as soil conservation, water security, gene pools, and can facilitate linkages between agricultural biodiversity and wildlife, thereby providing larger water/landscape integration.”
Under Section 41(1) of the Indian Biological Diversity Act, 2002, every local body in a state shall constitute a Biodiversity Management Committees (BMCs)\textsuperscript{28} within its area of jurisdiction for the purpose of promoting conservation, sustainable use and documentation of biological diversity including preservation of habitats. Out of 98 gram panchayats (village councils), 55 BMCs\textsuperscript{29} have been registered in Kargil until 2022, but they are largely inactive, partly because of a fundamental incomprehension as to their purpose, which is to transfer ownership and management of valuable resources to local communities. When planning the implementation of such schemes, it is proposed that Islamic terms such as Khalifa and Mizan should be deployed to facilitate communication. Additionally, a potential benefit of showing a willingness to engage with existing religious-cultural norms at the planning stage would be the possibility of winning over local religious leaders to the conservation cause. Having a local imam\textsuperscript{30} advocate for Khalifa and Mizan would surely be more impactful than anything an outsider could do.

As mentioned earlier, one of the most pressing issues facing the Dard-Shin population (and Ladakh at large) is effective water resources management, given the increasing rate of glacial melt. Glaciers are the primary source of water in this region. The imperatives of economic development and infrastructure for trade and commerce have led to careless decisions, such as the placement of a national highway next to the Parkachik glacier. Islamic law defines the area within 20 to 35 kilometres of Mecca and Medina as Harām, meaning it is an inviolable sanctuary. One could imagine a scenario whereby the elected members of the Ladakh Autonomous Hill Development Council in Kargil or the administration of the Union Territory define the area around the glaciers similarly.

**Conclusion**

In a region such as Kargil in the Trans-Himalaya, where the modern State has only recently encroached, modernity and science have far less legitimacy than older, more established belief systems that are not incompatible with the former. The Indigenous residents of this region have a long history of interacting with the larger world and have skilfully appropriated from foreign ideologies and religions where it has helped strengthen Indigenous systems for survival in a very harsh environment. Conservationists who wish to enlist the active participation of these communities are, therefore, well-advised to involve them in all stages of the co-productive conservation process. That can be best achieved by showing an appreciation and understanding of traditional knowledge and resource management systems. It would also require that practitioners familiarize themselves with Islamic thinking on environmentalism and sustainability. Having the ability to co-opt religious leaders and thinkers into the conservation cause, to engage them as active partners in the conservation process, listening respectfully to their opinions and taking them into account when designing an intervention, enlisting their participation in delivering the conservation message to the community at large, as well as jointly assessing the success of such collaboration will

\textsuperscript{28} As of 23 January 2024, there were 4658 BMCs in Jammu & Kashmir UT [http://nbaindia.org/content/20/35/1/bmc.html]

\textsuperscript{29} https://ladakh.gov.in/advisor-ladakh-chairs-the-first-meeting-of-ladakh-biodiversity-council-directs-for-the-immediate-constitution-of-biodiversity-management-committees/

\textsuperscript{30} The person who leads prayers in a mosque.
go a long way towards ensuring more impactful outcomes in the Trans-Himalaya.

References


Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

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<th>Contribution</th>
<th>Author 1</th>
<th>Author 2</th>
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<tr>
<td>Conceived and designed the research or analysis</td>
<td>Yes</td>
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<td>Collected the data</td>
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<td>Contributed to data analysis &amp; interpretation</td>
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<td>Wrote the article/paper</td>
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<td>Overall Contribution Proportion (%)</td>
<td>70</td>
<td>30</td>
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Research involving human bodies or organs or tissues (Helsinki Declaration)

The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)

The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

Research on Indigenous Peoples and/or Traditional Knowledge

The author(s) solemnly declare(s) that this research has involved Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge were only indirectly covered through literature review. Therefore, prior informed consent (PIC) of the respondents contained in Self-Declaration in this regard is appended with this written work.

Research involving Plants

The author(s) solemnly declare(s) that this research has not involved the plants for experiment and field studies. Some contexts of plants are also indirectly covered through literature review. Thus, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.
Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

Competing Interests/Conflict of Interest
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To see original copy of these declarations signed by Corresponding/First Author (on behalf of other co-authors too), please download associated zip folder [Declarations] from the published Abstract page accessible through and linked with the DOI: https://doi.org/10.33002/nr2581.6853.070102.
SELF-DECLARATION FORM

Research on Indigenous Peoples and/or Traditional Knowledge

1. Conditions of the Research

1.1 Was or will the research (be) conducted on (an) Indigenous land, including reserve, settlement, and land governed under a self-government rule/agreement or?

No

1.2 Did/does any of the criteria for participation include membership in an Indigenous community, group of communities, or organization, including urban Indigenous populations?

No

1.3 Did/does the research seek inputs from participants (members of the Indigenous community) regarding a community’s cultural heritage, artifacts, traditional knowledge, biocultural or biological resources or unique characteristics/practices?

Yes, one of the coauthors is Indigenous

1.4 Did/will Aboriginal identity or membership in an Indigenous community used or be used as a variable for the purposes of analysis?

No

2. Community Engagement

2.1 If you answered “Yes” to questions 1.1, 1.2, 1.3 or 1.4, have you initiated or do you intend to initiate an engagement process with the Indigenous collective, community or communities for this study?

Yes

2.2 If you answered “Yes” to question 2.1, describe the process that you have followed or will follow with to community engagement. Include any documentation of consultations (i.e., formal research agreement, letter of approval, PIC, email communications, etc.) and the role or position of those consulted, including their names if appropriate:

We work at the grassroots level with this community, but it’s on an informal basis. Even though the Dard-Shins are classified as a Scheduled Tribe, this classification comes with varying
degrees of autonomy, and in Kargil, this particular group is well integrated into the mainstream of society, so there is no need for any special permission to interact with them.

3. No Community Consultation or Engagement

If you answered “No” to question 2.1, briefly describe why community engagement will not be sought and how you can conduct a study that respects Aboriginal/Indigenous communities and participants in the absence of community engagement.

⇒ Name of Principal Researcher: Madhavi Peters
⇒ Affiliation of Principal Researcher: The Tropicalist Trust in Kargil. Reg No.: GAN-4-00557-2019-20. Ground Floor, Arjuman Manzil Near Govt Middle School Niyanto, Baroo, Kargil

Signature: 

Declaration: Submitting this note by email to any journal published by The Grassroots Institute is your confirmation that the information declared above is correct and devoid of any manipulation.

Roman Kirin\textsuperscript{1}, Petro Baranov\textsuperscript{2}, Hryhoriy Hrytsenko\textsuperscript{3}, Volodymyr Khomenko\textsuperscript{4}

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Abstract

Under this study, an interdisciplinary classification is developed concerning the entities of the gemological law. The classification is grounded in a symbiosis of criteria that define the content and scope of responsibilities, type of gemological activity undertaken, and the condition and appearance of a gemological object. The classification holds practical applications in mining, jewelry, business and management. Additionally, it can be employed in academic studies focusing on theoretical advancements in gemology, mineralogy, geology and jurisprudence. Introduction of this classification into the current legislation would enable both the entities of gemological law and law enforcement to integrally understand the spectrum, possibilities, forms and means of fulfilling their interests, along with their interrelations with other stakeholders. This research underscores that the primary criterion for developing an interdisciplinary classification of gemological law subjects is the type of gemological activity. Its symbiosis with other criteria, determining an entity’s responsibilities, as well as the condition and appearance of objects, establishes a practically reasonable and scientifically substantiated approach to the perception and understanding of this branch of gemological law. To propose to classify the entities of gemological law, three criteria may be: 1) content and scope of duties; 2) type of gemological activity; and 3) condition and appearance of a gemological object. It is important to note that this classification cannot and should not have strict limits, as entities of gemological relations exhibit inter-group features that manifest in general, group-classified, and direct levels of connections between administrative, mining, and economic relations. The dynamics within these relations can reflect the development and change of one kind of relation to another, along with the accompanying relations.

Keywords

Gemological law, entities, classification, gemological object, duties, gemological activity
Introduction

Making national gemological law, encompassing a set of respective norms and institutions aimed at regulating diverse gemological relationships, such as those involving the extraction, production, use, and storage of gemstones, as well as the oversight of related operations, require a certain subject content. This element stands out as a significant feature of social relations governed by gemological law norms. Theoretical and practical considerations regarding the notion, classification, and analysis of various aspects related to the entities of the law hold importance. Mere existence of these entities creates the imperative for the initiation and execution of gemological relations. In the society, relationships without an object and subject are non-existent, as the entities are integral in: 1) participating in gemological relationships; 2) possessing entity’s rights and legal duties; 3) exercising gemological rights through their actions; 4) creating and fulfilling gemological duties, while also bearing responsibility in case of non-compliance. Therefore, the issue of subject content of the gemological law, and thus the gemological legal relations, holds relevance for researchers in the field of gemology, mineralogy, geology and jurisprudence. It is equally pertinent for practitioners in mining and jewelry, state management, economic activity, and law enforcement.

Review of Literature

Gemology researchers have predominantly concentrated their investigations on specific participants within gemological relations, leaving others indirectly examined in the context of particular gemological activities. In particular, various articles make reference to participants such as jewelers and gemologists, who have no training in gemology. This scope extends to professionals working in gemological laboratories, sellers and buyers of jewelry (Shigley, 2008), as well as gemologists and mineralogists (Fritsch and Rondeau, 2009). Additionally, attention is directed towards workers involved in the extraction and processing of colored stones (Archuleta, 2016), researchers specializing in colored gemstones, participants in field expeditions, and institutions like the Gemological Institute of America (GIA) (Vertriest, Palke and Renfro, 2019). Further exploration includes mining management (Hilson, 2020), the State Service of Geology and Mineral Resources of Ukraine (Kirin, Baranov and Khomenko, 2020), geologists at emerald mines (Manyepa and Mutambo, 2021), and workers extracting gemstones, alongside geological companies (Sindelar, Barden and Stülp, 2021). According to the Ukrainian legislation, entities engaged in the extraction, production, use and storage of gemstones, as well as transactions involving them, are allowed to participate in economic activities in accordance with the law, irrespective of their property ownership form (Government of Ukraine, 1997\(^1\), hereinafter referred to as the Law on PM&GS).

Despite a quite substantial relevance of the raised question and the continuous usage of notions encompassed within the “entities of gemological law” category, existing articles have been only marginally and inadequately explored this subject.

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Simultaneously, it is crucial to acknowledge that the concept of “a subject of gemological law” necessitates a comprehensive analysis as a multifaceted phenomenon. While playing a pivotal role as an essential component of legal relations across various branches of the law, its specific characteristics may vary in each domain, particularly within gemological law and the intricate legal relationships emerging in gemology. Participation in the gemological legal relations requires any entity of gemological law to possess, at least three aspects: entitlement, legal capacity, and liability. For example, the State functions as an entity of the gemological law but engages in the gemological relations solely through its responsible bodies and officials. Furthermore, entities of the gemological law exhibit various facets of their existence, namely legal will, legal actions, legal consequences, legal consciousness, social-legal value, and more.

Currently, professionals from diverse fields have yet to undertake comprehensive research oriented towards defining the subject content of gemological law. It is essential to emphasize, however, that the present research examines the entities of gemological law within the context of their legal conduct as a precautionary measure. The objective of this study is the development of an interdisciplinary classification of entities within the gemological law. This classification is founded on a symbiosis integration of criteria that delineate the content and scope of their duties, nature of gemological activities they undertake, and the condition and appearance of the gemological objects involved.

**Methodology**

Research methodology includes general scientific and special methods. In particular, the methods of deductive and inductive thinking, as well as the method of generalization, were used as the main methods of cognition used in legal practice. Deductive thinking in the work was used from more general to more specific, inductive - on the contrary, moving from specific observations to broader generalizations and theories. The method of analysis of existing legal acts and objective assessment of current gemological legislation was chosen as the basis for writing this article. At the initial stage, it made it possible to formulate research questions and tasks, find an industry source base, conduct its audit, screening and selection for inclusion in the research subject. Subsequently, an assessment of the conformity or non-conformity of the selected acts with the topic of the article was carried out, as along with the extraction of the necessary prescriptions, and their analysis and systematization.

The research objectives were the key components on the basis of which the entire process of review, assessment and analysis of the current gemological legislation was carried out. They emphasized the type of information needed, relevant literature, and directed and oriented their further analysis. Below are the main research questions that were formulated before starting work on the main material: a) how to take into account the interdisciplinary nature of the subjects of gemological law when developing their classification? b) what criteria are basic and auxiliary in their differentiation? c) what factors influence the formation of classification levels and limits? d) how should the state and prospects of gemological legislation be considered? e) are there special subjects in gemological law?
We have attempted to cover the entire existing gemological legal framework as well as most of the relevant published studies to make the literature review a sufficient knowledge base. Legal acts were downloaded from web sources, mainly from the Information and Search System "Legislation" — the official off-line system of the Verkhovna Rada of Ukraine, and were stored separately. They were then screened and included or excluded based on the above research questions.

**Results**

The primary normative-legal document within gemological legislation, which establishes the fundamental principles and legal foundations for the State regulation of the extraction, production, use, and storage of gemstones, as well as the control of operations\(^2\), lacks a detailed breakdown of the general roster of entities in such relations. Additionally, it does not underscore their differentiation based on purposes. Instead, these entities are considered important elements around which legal relations in general and the gemological relations in particular revolve, serving as crucial components in both general legal connections and specifically within gemological contexts. Consequently, in accordance with the law, participants and law enforcement entities should perceive the spectrum, possibilities, forms and means of fulfillment their interests and their interrelation with other individuals. At the same time, the directives outlines in the Law on PMs&GSs, where the entities of gemological relations are exclusively are categorized as economic entities; fall short in fully elucidating their actual content. Furthermore, these instructions do not encompass entities explicitly mentioned in the text of the law.

Furthermore, when delineating the extensive domain of gemological law, it is imperative to scrutinize the intricate origins shaping its framework. Therefore, according to the categorization by the Ministry of Justice of Ukraine, the gemological legislation governing gemology and precious metals (PMs), under the title “Precious Metals and Gemstones” (code 110.120.050), fall within the ambit of normative-legal acts (hereinafter NLA), specifically categorized under “Currency Regulation” (code 110.120.000). This, in turn, is situated within the realm of financial-credit legislation (code 110.000.000 “Finances and Credit”) as per the directive of the Ministry of Justice of Ukraine (hereinafter – Minjust).\(^3\) Simultaneously, in the legislative structure proposed by the parliament's data-search system, “Legislation of Ukraine”, the gemological constituent (“Precious Metals, Gemstones” – code 20130 30) is not confined solely to the section “Currency Legislation” (code 20130) within the budget-financial legislation (code 20). It also finds placement in the industrial legislation (code 160 “Legislation on Activities of Industrial Spheres), specifically within the section addressing “Inventory checking, disposition of precious metals, diamonds and gemstones for industrial purposes” (code 160 20). Despite this divergence, considering that the latter group of the NLA largely mirrors the primary (financial) one, a structural connection is acknowledged between the financial and gemological legislations. In the same way, the nexus between gemological legislation and economic legislation is

\(^2\) Ibid

evident, as the Law on PMs&GSs designates entities of the economy as the primary entities governed by its regulatory framework.

However, an analysis of provisions within this legislative act provides grounds for identifying additional participants in gemological relations. First of all, attention should be given to a category of state collective entities for which a gemstone serves predominantly as a virtual object, encompassing that organize, regulate and administer the gemological activities. Despite the fact that the Law on PMs&GSs includes instructions regarding the state management (Article 3) and state regulation (Section II), there is unfortunately no dedicated article enumerating the subjects within the aforementioned group. Therefore, Article 3 of the Law on PMs&GSs addressing state management in gemological sphere, outlining the governing functions of the bodies of executive power (BEP) in Ukraine. While the law doesn't elaborate on these functions, two distinct articles focus on the central BEP: one provides the formation of the state financial policy concerning the regulation of extraction, production, use and storage of gemstones (Article 16), and the other relates to the central BEP overseeing the state policy in the sphere of the State Assay Control (Articles 16-1). This is governed by Ministry of Finances of Ukraine (Minfin), in accordance with the Resolution of the Cabinet of Ministers of Ukraine (CMU). The second functioned as the State Assay Control of Ukraine.

After liquidation of the latter in accordance with the government’s Resolution № 442 dated 10.09.2014, and its functions under the ambit of State Assay Control (hereinafter – SAC) were allocated to the Minfin, while protection of rights of consumers of gemstone goods was entrusted to the State Service of Food Safety and Consumer Protection of Ukraine (hereinafter – SSUFSCP). Nevertheless, the law makes no reference to the SSUFSCP. This legislative intricacy underscores not only the need for defining, organizing, and delineating the duties of state bodies power concerning gemological relations, but also the necessity for differentiation of competences between central and local branches of the representative power and the BEP. This requires presence of dedicated structural parts (chapters) within the Law on PMs&GSs that explicitly outline the duties of the Ukrainian Parliament, the Parliament of the Autonomous Republic of Crimea (hereinafter – ARC), and local government bodies (hereinafter – LG).

In the existing legal framework, for example, duties of the Cabinet of Ministers of Ukraine (CMU) in the gemological sphere are dispersed throughout the entire text of the law, touching upon the following types of relations:
– use and designation of valuables in the Historical Fund of the PMs&GSs of Ukraine.
– regulation of the formation and maintenance of the State Fund of PMs&GSs of Ukraine, along with its components – the Historical Fund, and determining the locations of these funds.


rules of trading GSs in raw and processed forms, as well as goods manufactured from them, owned by entities within the economic sector exercising property rights.

– sale of gemstones from the State Fund of PMs&GSs of Ukraine to economic entities.

– list of economic entities authorized to label domestically-produced goods with a state sample mark.

The Ministry of Finance (Minfin) serves as the central central body of executive power (BEP) oversee and coordinated by the Cabinet of Ministers of Ukraine (CMU). It holds a pivotal role as the principal entity within the central BEP system, responsible for shaping and executing the state policies related to the State Assay Control (SAC). Additionally, Minfin is instrumental in formulating and implementing state policies in the domains of extraction, production, use and storage of PM&GS, as well as their circulation and accounting. Moreover, depending on the designated duties, the Minfin:

– performs normative-legal regulations within the gemological sphere;

– orchestrates the work related to the establishment of the State Fund of the PMs&GSs;

– Implements the state policies pertaining to the SAC, focusing on the quality of PMs&GSs, goods derived from them, and materials containing them;

– undertakes the state regulation and monitoring to combat the illegal acquisition and laundering of profits specifically targeting economy entities engaged in cash trade involving PMs&GSs and goods related goods. The organizational structure of the Minfin encompasses the Management of State Policy in the sphere of SAC, which, in turn, comprises two units. One of these units is responsible for state regulation in the production, utilization, and storage of PMs&GSs.

The entities falling within the purview of the Minfin’s management sphere include the State Gemological Center of Ukraine (SGCU), the State Institution Museum of Precious and Decorative Stones (MPDS), the State Institution State Repository of Precious Metals and Gemstones (State Repository of PMs&GSs), and the State Enterprises of Assay Control (SEAC) having branches in Dnipropetrovsk, Donetsk, Western, Southern, Eastern and Central parts. Unlike the Minfin, these entities primarily engage with tangible gemstones and goods derived from them, collectively constituting a group of entities of use, expertise and utilization of GSs for scientific purposes, social-cultural needs, investment requirements, and more.

According to the legislation, the State Gemological Control Unit (SGCU) is mandated to – undertake various responsibilities, including the independent assessment and quality control of raw materials and products composed of gemstones (GSs), as well as items incorporating them. Additionally, the SGCU conducts expert evaluations of GSs classified in the State Fund of PMs&GSs of Ukraine. It offers methodological help to geology-surveying, mining and processing enterprises, aiming to enhance the quality of their work and methodological support. The unit is also involved in gemological studies of raw materials and undertakes other tasks assigned by relevant authorities in connection with the independent evaluation of GSs. Operating within the management sphere of the Minfin, the SGCU follows the guidelines established in the approved Order by the Government of Ukraine.7

Ibid

The State Repository of PMs&GSs is a government institution created by the CMU for purchases of PMs&GSs in any form or condition, utilizing funds from the state budget. The repository is entrusted with the responsibilities of receiving, storing, selling and maintaining records of these assets, including those held within the State Fund of PMs&GSs of Ukraine. The primary objective of the Museum of Precious and Decorative Stones (MPDS), as outlines in the Government of Ukraine’s directive is reliable preservation of its collection and the gathering of scientific mineralogical materials from both Ukrainian and international deposits. Additionally, the museum is dedicated to promoting scientific knowledge and popularizing gemological achievements. Since 2001, the museum has been recognized as a scientific entity with the status of National Heritage of Ukraine.

The second category within gemological law comprises entities under the state control within the domain of PMs&GSs. These entities operate in two primary facets: 1) state assay control of the quality of PMs&GSs and goods derived from them; 2) supervision of operations concerning PMs&GSs, involving tasks such as: 2.1) monitoring gemological business entities; 2.2) overseeing the compliance with the Kimberley Process Certification Scheme for rough diamonds, and 2.3) ensuring the quality control of measurements in laboratories of economic entities.

The law identifies two main entities involved in gemological control. The first category comprises institutions such as the Accounting Chamber of the National Bank of Ukraine (NBU), Minfin, and other BEPs as part of their specified duties outlined by the legislation of Ukraine. The second category includes entities under gemological control, namely: economic entities engaged in the extraction, processing and use of PMs&GSs, as well as those involved in purchasing, accepting jewelry and household items made of PMs&GSs as collateral in exchange for loans, trading these items, providing intermediary services in trade, storing and displaying various items containing theses valuables, and handling the collection and recycling of waste and scraps of PMs&GSs. Additionally, this category encompasses military bases, units, organizations and institutions of the Ministry of Defence of Ukraine, the National Police of Ukraine (NPU), the Security Service of Ukraine, and organizations and institutions of other central BEPs.

The State Service for Consumer Rights Protection (SSUFSCP) serves as an entity responsible for conducting state monitoring and control to ensure compliance with consumer rights legislation, specifically concerning buyers of goods made of PMs&GSs. Additionally, the Minfin and the NBU are also entities engaged in purchasing and trading operations involving PMs&GSs and other valuables, both

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domestically and internationally, without being constrained by quotas or licensing requirements. Furthermore, the NBU assumes the role of a storage entity for GSs.\(^{10}\)

Another category of subject within gemological law comprises entities specializing in gemological expertise. As per the examination of the Law on PMs&GSs, such an expertise is conducted in instances involving the placement of valuables in the Historical Fund of PMs&GSs of Ukraine. Additionally, gemological expertise is carried out for the evaluation of inlays of gemstones and museum items containing gemstones. The State Gemological Control Unit (SGCU) is responsible for independent expertise and control of quality of raw material and GS goods, as well as goods containing them, including expert evaluation of GSs.

Furthermore, authorized representatives of the SGCU are actively involved in conducting essential expertise and processing accompanying documentation during customs clearance procedures for rough diamonds entering the customs territory of Ukraine and for diamonds being exported from the customs territory of Ukraine.\(^{11}\) Various entities participate in these transactions, including the body responsible for import, the exporting body, the receiver (importer), and the sender (exporter). Furthermore, the SGCU assumes the responsibility for the registration of certificates and addressing other issues related to the implementation of the requirements outlined in the Kimberley Process Certification Scheme in Ukraine.\(^{12}\) Additionally, training to become a gemology expert and also work related to the expertise of GSs is paid for according to the tariffs approved by Order № 593 of the Minfin as of 24.06.2015 (version № 725 as of 30.12.2021).

The assessment of estimated and insurance values for museum items of the Ministry of Culture and Information Policy of Ukraine (MCIP) is carried out through the purchasing-fund commissions of the museums, involving experts and specialists. Specifically, for items containing GSs, experts from the State Expertise and Appraisal Center (SEAC) and SGCU authorized for such tasks in accordance with government regulations perform the necessary assessments.\(^{13}\) Additionally, the expertise of GS inlays and museum items containing GSs can be carried out by the SEAC, as well as legal and physical entities functioning as economic entities (Government of Ukraine, 1999b). According to the order of the Ministry of Culture of Ukraine, entities

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14 Government of Ukraine (1999b). *On the approval of the Instructions on the procedure for stamping jewelry and household products made of precious metals, on conducting tests and examinations of precious metals, products made from them, gemstones inserts, museum objects containing precious metals*.
utilizing the findings of gemological expertise include the participants in the state expertise of cultural valuables. This encompasses applicants, organizers of expertise, experts, and experts and art historians.15

Finally, the category of entities involved in gemological expertise and forensic activities, defined by corresponding legislation, encompasses forensic experts from the Scientific Research Institute of Forensic Expertise (SRIFE), the Minjust, and the State Scientific Research Forensic Center (SSRFC) of the Ministry of Internal Affairs of Ukraine (MIA). These entities, identified in the corresponding legislation, undertake gemological expertise, expert studies and evaluation of GSs (Kirin et al., 2023).

Entities engaged in the certification of GSs can include economic entities conducting operations with GSs or incorporating them into their activities. Persons involved in the certification must possess the relevant qualifications. The certification process of GSs is carried out at various critical stages, including the final phases of mining (for GSs sourced from Ukrainian deposits), processing and the production of goods from these mineral reserves. If certification by the aforementioned entities is not feasible, an agreement can be reached for certification through the SGCU as stipulated.16

Economic entities undergoing privatization (corporatization) and the body of privatization (specifically, the State Property Fund of Ukraine or SPFU) are identified as the entities responsible for evaluating PMs&GSs within state and municipal properties. These evaluations are essential for the inclusion of PMs&GSs in the authorized funds of economic entities, as well as in property of lessees when introduced into the authorized fund of a joint-stock company managing a leased enterprise.17 The methodological recommendations of the Minfin determine the entities responsible for accounting for PMs&GSs, including the sender (providing scraps and wastes to other entities) and the receiver (receiving scraps and wastes from other entities for further primary processing or recycling).18


The latter groups of entities highlight that the primary criterion for developing an interdisciplinary classification of entities within gemological law is the type of gemological activity. This criterion, when combined with other factors determining the duties of entities, as well as the condition and appearance of gemological objects, suggests the most practically justified and scientifically substantiated approach to understanding and interpreting this facet of the gemological law. A specific bylaws of the the National Legislation Acts (NLA) that distinctly identifies various types of gemological activity is the resolution issued by the Minfin. This resolution outlines the procedures for accounting, creating and implementing a register of economic entities engaged in operations with PMs&GSs. These activities encompass the production of PMs&GSs, crafting jewelry and household goods using PMs&GSs, repairing jewelry and household items with PMs&GSs, making household goods using PMs&GSs, (including instruments and technical goods with natural diamonds), trading (wholesale, retail, commission) of PMs&GSs and goods containing PMs&GSs, exchanging jewelry and household goods with PMs&GSs for PM scraps, utilizing PMs&GSs for production, scientific, socio-cultural needs and investment purposes, pawnshop operations involving PMs&GSs, purchasing PMs&GSs, faceting and other processing of GSs, including diamond faceting, collection and primary processing of PMs&GSs wastes and scraps, and ongoing exposition of PMs&GSs.\(^{19}\)

The given list is more extensive than the legislative enumeration found in Article 1 of the Law on PMs&GSs, yet it does not fully align with the directives of the law. Firstly, within the law, the term “operations with PMs&GSs” specifically denotes gemological activities. Secondly, these actions encompass various aspects, including: a) emergence and suspension of the property rights and other rights to GSs, such as acceptance jewelry and household goods with PMs as collateral for loans; b) the entry of GSs into designated storage locations, their maintenance, and their disposal in a predetermined manner; c) alteration in the content or physical condition of GSs as they undergo extraction, production and usage; c) the import and export of GSs, goods and materials containing them to and from Ukraine; and d) the maintenance and exhibition of GSs.

Therefore, recognizing that certain entities engage in conducting operations with gemological objects – GSs with specific content, appearance and/or conditions - there is a rationale to designate a set of entities within gemological law based on the criterion of a gemological object. These categories include:

1) entities involved with natural minerals in their raw form;
2) entities dealing with natural materials in unprocessed state;
3) entities dealing with natural minerals in processed forms (goods);
4) entities dealing with artificial (synthetic) minerals in raw materials;
5) entities dealing with artificial (synthetic) minerals in raw form;
6) entities managing artificial (synthetic) minerals in processed form (goods).

Moreover, it is essential to distinguish entities involved in the production of gemological goods, dividing them into:

- entities manufacturing GS goods (using one or a combination of several types);

– entities producing goods containing GSs (for example, GS inlays). It is noteworthy that the analysis of gemological objects themselves was previously conducted by the authors in a previous study (Kirin, Baranov and Koziakov, 2022).

Such an approach facilitates a more comprehensive examination of entities utilizing and applying GSs for individual purposes. To achieve this, it is essential to consider the position outlined in the Economic Code of Ukraine (ECU). As per Article 2 of the ECU, participants in the economic sphere encompass: 1) entities of economy; 2) consumers; 3) bodies of state power and the local governments vested with economic authorities; 4) citizens, non-governmental organizations acting as founders of economic entities or fulfilling organizational-economic duties based on the property ownership rights. However, not all individuals falling under these categories are considered entities of economic legal relations; they are participants in economic gemological relations requiring a specific set of attributes. In the sphere of economy who have a complex of necessary features. Consequently, entities recognized as participants in economic gemological relations are those that: a) directly engage in economic activities or manage such an activities; b) have been established in accordance with the law; c) possess the necessary property to perform economic activities; d) have economic legal personality.

Coinciding the nature of activity, it is justified to designate the entities into the following groups:

1) entities of the economy directly involved in gemological activity, termed as subjects of economic-production relations;
2) entities with organization-economic duties responsible for organizing and managing gemological activity, identified as subjects of organization-economic relations.

In this context, as defined in the ECU, economic-production gemological relations encompass property and other relations that arise among subjects of the economy during the direct execution of economic gemological activities. On the other hand, organization-economic gemological relations are those that evolve between subjects of the gemological economy and entities with organization-economic duties during the management of gemological economic activities. Building upon the preamble of the Law on PMs&GSs, there is justification for further differentiation in the subject circle of gemological relations. This includes:

1) subjects of mining – entities involved in extraction of GSs from rocks using all available means.
2) subjects of use – entities that recycle, process, use, and apply GSs for production, scientific, socio-cultural and investment purposes.
3) subjects of circulation – entities conducting operations with PMs&GSs.

The category of subjects of circulation unmistakably encompasses those involved in maintenance, as well as partially includes subjects of use and subjects of production. Though the concept of “production of GSs” lacks explicit definition in the Law on PMs&GSs, it becomes imperative to conduct a more detailed study due to inherent ambiguity. This ambiguity is evident in Article 189-1 of the Code of Ukraine on Administrative Violations, titled “Violations of order of extraction, production, use and selling of precious metals and gemstones, gemstones of organogenic formation and
Roman Kirin, Petro Baranov, Hryhoriy Hrytsenko, Volodymyr Khomenko

semiprecious stones”. Therefore, a more detailed exploration is warranted to enhance clarity and understanding of the term within the legal framework.

The entity responsible for coordinating the extraction of GSs and entity responsible for coordinating the state reserve for mined deposits of PMs&GSs at a broad level is the State Geological and Subsoil Survey of Ukraine (UGS). Among the group-classified subjects overseeing the organization of GS extraction, structural units within the UGS play a crucial role. Notably, these include the Department of the State Geological Control and interregional units (Central, Eastern, Western, Southern, Azov-Black Sea, Northern), as well as the Unit overseeing mineral resources utilization and management of procedures for granting special approvals. Officials at the general and group-classified levels constitute the direct operational tier within the entities responsible for organizing the extraction of GSs.

As an example of an entity engaged in production activities through the extraction of GSs, one can highlight the State Enterprise Amber of Ukraine. Its primary operational focus aligns with the classification of DK 009:2010, specifically falling under Section B:

- Extracting industry and mining of quarries;
- Within this classification, it corresponds to Section 8;
- Extraction of other fossils and mining of quarries;
- Group 08.9 - Extraction of fossils and mining of quarries;
- Class 08.99 - Extraction of other mineral resources and mining of quarries (not included in other groupings).

Among other things, these classes comprises various mining activities, whether underground or open, involving diverse minerals and materials such as GSs, quartz, mica, etc. In addition to its extraction pursuits, the enterprise is also certified for activities like 32.12 - Production of jewelry and similar goods, and 09.90 - Provision of additional services in the sphere of extraction of other mineral resources and quarrying, demonstrating a diversified operational portfolio.

Applying the same underlying principle, it is suggested to categorize the entities involved in the recycling and processing of GSs, including primary processing tasks such as sorting, division, pyrotechnical and radiation controls. Additionally, entities engaged in the recuperation of GSs, involving the return of a portion for reuse, should be designated accordingly. The composition of participants is distinctive, comprising both primary and ancillary entities governed by gemological law dealing with GSs as commodities. Such participants extend to individuals taking part in organizing retail and auction trade of antique items. This includes entities of the economy overseeing the commission and sale of antique items through specialized consignment stores, dedicated sections of consignment stores, and specific

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consignment sections within stores offering a broad range of non-grocery goods. Moreover, participants involve workers of economy entities serving the buyers, auction organizers, auction commissions (comprising roles such as head, accountant, commodity expert, cashier, lawyer, archivist, art historians, and other specialists categorized under signed labour agreements (contracts). Entities such as the owners of antique items, facilitators, and auction host are integral parts of this intricate network. The trade of GSs, trade of GSs, both in raw and processed forms, and goods associated with them, by entities holding property rights, is regulated by the Rules outlines in the resolution of the CMU dated 04.06.1998 № 802 (as of 25.01.2017, № 41). It is noteworthy that this activity can also be carried out through distance communication means, as specified by the same Rules. Furthermore, these Rules govern the relationship between consumers and sellers concerning the specified types of GSs.

The geology-centric subjects, museum affairs within the Ministry of Defence of Ukraine (hereinafter – Mindefence) can be classified as:
– military museum;
– military-museum networks;
– museum formation;
– a branch of military museums.

These museums are entitled to to form national, regional and specialized organizations (unions, associations, etc.), and may also join international museum organizations and funds.

Recipients of national awards in Ukraine, whether citizens, foreigners, or stateless persons, with awards made of PMs and/or GSs, are permitted to transport those awards abroad if they possess the necessary documentation outlined in the Order issued by the CMU on 21.06.2001 № 677. The export of GSs and goods made containing them outside the customs territory of Ukraine, for the purpose of disposition, is carried out through actions, verbant agreement, and the owner’s explicit will or written declaration, as required by a customs service official, following the regulations established in the CMU-approved Order of 21.05.2012, № 448. Finally, the entities responsible for protecting PMs&GSs during their extraction, production, processing, trade and export, as well as goods derived from them, in the specified order, are:

– bodies of the National Police of Ukraine (NPU);
– organizations holding licenses for such activities as mandated by the legislation;
– employees of relevant enterprises.

**Discussion**

When delineating the circle of subjects involved in the social-legal administering of the circulation of PMs&GSs, Titova (2021) introduced a classification based on the scope of their competencies. These are categorized as follows: 1) entities with general

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competence, including the Ukrainian Parliament, the President of Ukraine, CMU, local BEPs and local governments (LGs); 2) bodies engaged in interdisciplinary public administration, such as the Ministry of Economy of Ukraine (Mineconomy), the Ministry of Internal Affairs (MIA), Ministry of Environment and Natural Resources of Ukraine (Minenvironmental), State Customs Service of Ukraine and other; 3) subjects of interdisciplinary public administration (special public administration), including entities like Minfin, State Fiscal Service of Ukraine, The State Service for Consumer Rights Protection (SSUFSCP), State Geological and Subsoil Survey of Ukraine (UGS), and the State Service of Ukraine for Geodesy, Cartography and Cadastre (StateGeoCadastre); 4) legal entities of public law, represented by, such as, State Gemological Control Unit (SGCU), State Repository of PM&GS, MPDS, and the Enterprises of State Assay Control (SAC) (Titova, 2021).

However, this depiction of the system of subjects of public-legal administration within the sphere of PMs&GSs domain has elicited various comments and objections. First of all, in the given list, the State Fiscal Service of Ukraine had undergone reorganization resulting in the establishment of the State Tax Service of Ukraine (STS) and the State Customs Service (SCS) as per order № 1200 of the CMU dated 18.12.2018. Secondly, both the entities are central BEPs, whose activities are oriented and coordinated by the CMU through the Minfin. Therefore, the SCS cannot be categorized as a subject of interdisciplinary public administration, and the State Tax Service should note be considered a subject of sphere-related public administration since both fall under the jurisdiction of Minfin. Thirdly, for the mentioned legal entities of public law, in general, no specific sphere of duties was outlined, leading to a lack of a defined position in the classification. Taking into account that all of them are state institutions within the purview of Minfin management, their competence should align with that of central BEPs. Thus, they should be recognized as subjects of interdisciplinary public administration. Fourthly, it should be considered that the classification was incorrect if the UGS and StateGeoCadastre are grouped into entities of sphere-related public administration. These central BEPs are responsible for implementing state policies in the areas of mineral reserves and land relations concerning all kinds of mineral resources. Hence, they should be categorized as having an interdisciplinary status within the public-legal administration framework of the PMs&GSs circulation sphere.

The structurally integrated entities within gemological law exhibit a more ramified classification. As previously mentioned, this complexity arises from the fact that the Minfin covers a gemological management, which, in turn, houses a gemological unit. Moreover, Article 20 of the Law on PMs&GSs designates officials of the regulatory bodies as the entities responsible for state control over operations involving PMs&GSs. Therefore, it is advocated that for a more justified division, wherein subjects from each group are further classified into respective subgroups. These subgroups would unite the general entities (such as Minfin), category-related entities (including management, unit), and direct entities (comprising officials). It is crucial to note that such a classification lacks distinct boundaries, given that subjects involved in gemological legal relations exhibit inter-group features that manifest specifically at respective levels of connections within administrative, mining and economic realms.

Concerning the array of entities engaged in specific types of gemological activities, it is essential to highlight the provisions outlined in Part 3 of Article 15 of the Law on
PMs&GSs. This section specifies that entities responsible for certifying laboratories associated with economic entities involved in the production of jewelry and household goods may include both the Ministry of Economics of Ukraine and Minfin. However, it is pertinent to note that as of 01.01.2016, the Law of Ukraine “On Metrology and Metrological Activity,” took full effect, leading to the liquidation of the national System of Certification of Laboratories. Simultaneously, a framework for voluntary accreditation of calibration and testing laboratories, bodies conducting conformity assessments as specified by this particular law and other Ukrainian statutes, was introduced. Therefore, entities tasked to conforming or recognizing the competence of laboratories, in accordance with the State Standards, encompass laboratory clients, regulatory bodies, organizations and project developers utilizing expert conclusions, and bodies of accreditation bodies.24

It is crucial to highlight a distinctive category of GS in Ukraine that holds a unique legal status. The legal framework governing gemstones, such as amber, spans various legislative spheres, each addressing specific aspects related to its extraction and utilization. In particular: 1) the administrative legislation identifies responsibilities for violations related to the extraction; 2) the laws on the natural resources and mining eliminate the necessity of obtaining an act for provisions with mining allotment to a user of amber-bearing reserve with special permission for using such natural reserves; 3) the criminal legislation establishes penalties for illegal extraction, sale, purchase, disposition, dispatch, transfer, and processing of amber; 4) the land legislation specifies obligations for users involved in amber-bearing natural resources performing surveys and/or mining, including the primary right to land use for those having special permission; 5) the customs legislation outlining new tariffs for unprocessed and processed forms of amber, agglomerated amber (ambroide), and items manufactured from them.25 Furthermore, the tax legislation identifies the rent size applicable to amber mining from natural resources. Consequently, a distinct subject has emerged in gemological legislation, namely user of amber-bearing resources.

Table 1: Classification of entities of gemological law (classification criteria)

<table>
<thead>
<tr>
<th>Classification groups of subjects</th>
<th>Group representative</th>
<th>Functional area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Content and scope of powers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1) entities of general powers</td>
<td>Verkhovna Rada of</td>
<td>General regulation of gemological relations</td>
</tr>
<tr>
<td></td>
<td>Ukraine, President</td>
<td></td>
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<tr>
<td></td>
<td>of Ukraine, CMU,</td>
<td></td>
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<td></td>
<td>local</td>
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<td></td>
<td>BEP and LG</td>
<td></td>
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<tr>
<td>1.2) entities of inter-sectoral powers</td>
<td>Mineconomy, MIA,</td>
<td>Inter-sectoral management in the field</td>
</tr>
<tr>
<td></td>
<td>Minenvironmental,</td>
<td>of gemological relations</td>
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</tbody>
</table>


### Classification groups of subjects

<table>
<thead>
<tr>
<th>Group representative</th>
<th>Functional area</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGS, StateGeoCadastre, SSUFSCP</td>
<td></td>
</tr>
<tr>
<td>1.3) entities of sectoral powers</td>
<td>Sectoral management in the field of gemological relations</td>
</tr>
<tr>
<td>Minfin, STS, SCS</td>
<td></td>
</tr>
<tr>
<td>1.4) entities of intra-sectoral powers</td>
<td>Intra-industry transactions with GS</td>
</tr>
<tr>
<td>SGCU, State Repository of PM&amp;GS, MPDS, Enterprises of SAC</td>
<td></td>
</tr>
<tr>
<td>1.5) entities of related to gemological powers</td>
<td>Management in the field of related to gemological relations</td>
</tr>
<tr>
<td>Minjust, Mindefence, MCIP, SPFU</td>
<td></td>
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</tbody>
</table>

### 2. Nature of the gemological activities carried out

<p>| 2.1) entities that organise and manage gemological activities (regulation, control over operations) | Minfin | Formulation of the state GS-policy, implementation of the state SAC policy |
| Accounting Chamber, NBU, Minfin and other BEP | SSUFSCP | Implementation of state supervision (control) over compliance with the legislation on consumer protection of PM&amp;GS products |
| SGCU | State repository of PM&amp;GS, MPDS, Enterprise of SAC | State control over diamond transactions in accordance with the requirements of the Kimberley Process Certification Scheme; quality control of measurements in laboratories of business entities. Independent gemological examination and quality control of raw materials and products made of GS, as well as products with them, expert assessment of GS |
| | State repository of PM&amp;GS, MPDS, Enterprise of SAC | Use and application of GS for scientific, social, cultural and investment needs |
| 2.2) entities directly engaged in activities aimed at manufacturing and selling gemological products, performing gemological works or providing gemological services (mining, production, | Minfin, NBU | Purchase and sale of PM&amp;GS, other jewellery on the domestic and foreign markets, storage of GS |
| | SEAC, Business entities | Expertise of GS inserts, museum objects containing GS |
| | Applicants, Organizers of expertise, Experts and Art Critics | State expertise of cultural property |
| | SRIFE of Minjust, SSRFC of MIA | Forensic gemological expertise |</p>
<table>
<thead>
<tr>
<th>Classification groups of subjects</th>
<th>Group representative</th>
<th>Functional area</th>
</tr>
</thead>
<tbody>
<tr>
<td>use, storage, etc.;</td>
<td>SGCU, Business entities</td>
<td>GS certification</td>
</tr>
<tr>
<td>SPFU, Business entities</td>
<td></td>
<td>PM&amp;GS assessment</td>
</tr>
<tr>
<td>Business entities, sender and receiver</td>
<td></td>
<td>PM&amp;GS accounting</td>
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<tr>
<td>Fund and purchase</td>
<td></td>
<td>Determining the appraisal and insurance value of museum objects</td>
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<td>Commissions of Museums</td>
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<tr>
<td>NPU, Business entities</td>
<td></td>
<td>PM&amp;GS security</td>
</tr>
<tr>
<td>Business entities</td>
<td></td>
<td>Operations with GS: production, manufacturing and repair of jewelry and household goods, manufacturing of industrial goods, including the manufacture of tools and other technical products from natural diamonds, trade (wholesale, retail, commission) in GS and GS products, exchange of finished jewelry and household items for PM scrap, use of GS for production, scientific, social and cultural needs and investment purposes, pawnshop operations, purchasing, cutting and other processing of GS, including diamond cutting, collection, primary processing of waste and scrap, and storage, importing GS, products and materials containing them into Ukraine from abroad and exporting them from Ukraine, exhibiting GS on a permanent basis.</td>
</tr>
</tbody>
</table>

3. Condition and appearance of a gemological object

<table>
<thead>
<tr>
<th>3.1) entities handling natural minerals in raw materials</th>
<th>UGS, Business entities</th>
<th>Mining organization, GS mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2) entities handling natural minerals in their unprocessed form</td>
<td>Business entities</td>
<td>Sorting, separation, pyrotechnic and radiation control GS</td>
</tr>
<tr>
<td>3.3) entities handling natural minerals in processed form (products)</td>
<td>Business entities, Consumers</td>
<td>Processing, treatment, recovery of GS, other operations with GS, products made of GS and products containing GS, organization of trade in antiques in the retail network and at auctions</td>
</tr>
<tr>
<td>Museums</td>
<td>GS exposure</td>
<td></td>
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<tr>
<td>Citizens of Ukraine,</td>
<td>Removal of state awards from PM</td>
<td></td>
</tr>
<tr>
<td>Classification groups of subjects</td>
<td>Group representative</td>
<td>Functional area</td>
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<tr>
<td>3.4) entities handling artificial (synthetic) minerals in raw material</td>
<td>Business entities</td>
<td>Production of artificial (synthetic) minerals in raw materials</td>
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<tr>
<td>3.5) entities handling artificial (synthetic) minerals in their raw form</td>
<td>Business entities</td>
<td>Sorting, separation, pyrotechnic and radiation control of artificial (synthetic) minerals in raw form</td>
</tr>
<tr>
<td>3.6) entities handling artificial (synthetic) minerals in processed form (products)</td>
<td>Business entities</td>
<td>Manufacture of industrial products, including tools and other technical products</td>
</tr>
<tr>
<td>3.7) Amber handling entities</td>
<td>Business entities</td>
<td>Mining, sale, acquisition, transfer, forwarding, transportation, processing of amber</td>
</tr>
</tbody>
</table>

**Conclusion**

The conclusion is in 6 highlighted points, which are as follows:

1. In this article, an interdisciplinary classification of entities of gemological law is developed, grounded in the fusion of criteria determining the content and scope of their duties, the nature of conducted gemological activities, and the condition and appearance of the gemological objects under consideration. This classification holds practical utility in diverse domains such as mining jewelry production, business, and administration. Additionally, it serves as a valuable tool in academic pursuits aimed at advancing theoretical frameworks in gemology, mineralogy, geology, and jurisprudence. Implementing this classification into the current legislation would facilitate a comprehensive understanding for both entities within gemological law and law enforcement stakeholders, enabling a holistic grasp of the circle, opportunities, forms and methods involved in safeguarding the interests of participants in relevant relationships. Moreover, it would enhance comprehension of the intricate interrelations among individuals involved in gemological law.

2. Evidences are presented supporting the assertion that the criterion of the type of gemological activity performed is fundamental to the development of an interdisciplinary classification for entities within the gemological law. Its integration with other criteria determining the responsibilities of entities, as well as the condition and appearance of gemological objects, establishes the most practically justified and scientifically substantiated approach to comprehending and interpreting this facet of gemological law. The production activities of economic entities in the field of gemology encompass efforts directed at creating and selling gemological products, executing gemological work, or providing gemological appraisal services, all assessed in terms of their monetary value. According to the directives of economic legislation, the production of gemological relations is construed as property relations and other
connections arising among entities during the direct execution of economic gemological (productive) activities. The organizational gemological relationships, on the other hand, pertain to connections emerging between entities in the gemological economy and those with organization-gemological duties in the management of productive gemological activities.

3. A classification systems for subjects within gemological law is proposed based on the following criteria:

1) Content and scope of duties:
   1.1) subjects of general duties;
   1.2) subjects of interdisciplinary duties;
   1.3) subjects of sphere-related duties;
   1.4) subjects of within-a-sphere duties; and
   1.5) subjects of gemology-centric duties.

2) Pattern of performed gemological activity:
   2.1) subjects involved in the organization and management of gemological activities (regulation, control of operations); and
   2.2) subjects directly engaged in activities related to the production and sale of gemological products, the execution of gemological work, or the provision of gemological services (extraction, production, use, storage, etc.).

3) Condition and appearance of a gemological object:
   3.1) subjects dealing with natural minerals in raw material;
   3.2) subjects dealing with natural minerals in an unprocessed form;
   3.3) subjects dealing with natural minerals in a processed form (goods);
   3.4) subjects dealing with artificial (synthetic) minerals in raw material;
   3.5) subjects dealing with artificial (synthetic) minerals in an unprocessed form;
   3.6) subjects dealing with artificial (synthetic) minerals in a processed form (goods); and
   3.7) subjects dealing with amber (refer to Table 1).

4. The classification presented by Government of Ukraine lacks distinct boundaries due to the inter-group features inherent in subjects of gemological legal relations. These characteristics become particularly evident at broader, group-related levels of connections within administrative, mining and economic relations. The dynamics of these relations can signify the evolution and transformation of one type of relations into another, along with the accompanying relationships that emerge. Such an interdisciplinary legal nature is a common trait not only in gemological law but also in other legal domains that regulate complex objects, marked by a network of relations involving diverse material resources
   — whether natural, recycled, and/or processed
   — across various stages of economic development

5. Viewing the gemological legislation as a complex institution with budgetary and financial, industrial, economic legislation, and legislation related to mineral resources has been suggested. Its current reform should encompass, among other aspects, the
refinement of specific structural components (chapters) within the gemological law. These chapters would distinctly unpack the duties of key entities such as the Ukrainian Parliament, the Parliament of the Autonomous Republic of Crimea, local government bodies, and executive authorities responsible for regulating gemological relations.

6. Arguments are put forth supporting the recognition of distinct entities in the gemological law, particularly the user of amber-bearing resources. The legal status of this entity is enshrined in a complex set of regulations inculcating gemological, administrative, criminal, customs, tax, budget, mining, land, and resource legislation. No other type of gemological object in Ukraine is subject to such an extensive legislative framework. It is recommended to establish a systemic structure for the subject scope of the user of amber-bearing resources within the Law of Ukraine on Amber.

References


Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

<table>
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<tr>
<th>Contribution</th>
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<th>Author 2</th>
<th>Author 3</th>
<th>Author 4</th>
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<td>Collected the data</td>
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<td>Contributed to data analysis &amp; interpretation</td>
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<td>Wrote the article/paper</td>
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<td>25</td>
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
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Extracting Insoluble Inorganic Phosphorus from Organic Farm Soils in Mountains: Identifying Effective Organic Acid Extractants

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Abstract
Phosphorus, among others, is quite a vital nutrient for the life of a plant. Because of the dominance of iron and aluminium oxides in acidic soils, they facilitate the fixation of phosphorus which results into phosphorus deficiency in large amounts. Hence, proper replenishment of the soil phosphorus (P) is very much important to cater the need of plant P requirement for better yield and development. The agricultural soils of Meghalaya (India) are by default rich in organic contents and organic P pool contributes 15-80% of the total plant P nutrition. Moreover, a different nature of nutrient pools is present in organic farming system compared to the conventional farming system. Lack of knowledge of these pools results in an imbalanced manuring plan, which hinders successful production system. The dynamic fraction of P cannot represent the correct status of phosphorus in soils under organic production systems, as the conventional soil testing protocols do not take into account the potentially available inorganic pools of phosphorus. Hence, a different extractant that can extract such potentially available P in an acidic soil under organic production system is highly required. The mineralization, solubilization and extraction (of the potentially available P pool) by using various organic acids produced through the beneficial soil microorganisms can serve this purpose. Therefore, the present research work was carried out to identify the best suitable P extractant to extract such potentially available inorganic P pool. The result of the present investigation revealed that out of 6 different extractants selected, 2% citric acid and double lactate extractants were found to be strongly correlated to the total P of the selected sites. Conventional Bray 1 extractant was taken as a check extractant. The outcome of the research is to develop a proper recommendation of fertilizer dose and an appropriate soil testing protocol for phosphorus being used in organic cultivation.

Keywords
Phosphorus; Pools; Extractants; Organic farming system; Soil testing protocol
Introduction

Mountains cover almost 24 percent of the Earth’s surface supporting around 3 billion people worldwide through food, fresh water, shelter, hydropower, indigenous/local industries, etc. Hill and mountainous areas in India are vastly distributed all over the country with a larger area located in Himalayas, extending up to 2,500 km in length and 250-400 km in breadth. About 30 percent of the total land area in India is occupied by mountains covering mainly the parts of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Assam, and other North-Eastern states along with West Bengal. The dominant features of hill or mountain farming in North-East Himalayas are small landholdings, sloping marginal land, rainfall-dependent farming and shallow soils prone to erosion. The North-Eastern states of India are particularly hilly and are mostly covered by forests and hills, such as Garo hills, Lushai hills, Patkai hills, Khasi hills, Jaintia hills, Naga hills, etc.

India holds a unique position among 172 countries practicing organic agriculture. It has 6,50,000 organic producers, 699 processors, 699 exporters and 7,20,000 hectares under cultivation (Goyal, 2019). But, with merely 0.4% of total agricultural land under organic cultivation, the industry has a long journey ahead. India produces around 1.35 million tonnes (2015-16) of certified organic products which includes all varieties of food products (Jha, 2017). The country ranked first in terms of the number of organic producers among over 170 countries and ninth in terms of the area under organic agriculture. India ranked eleventh in organic product exports in 2015. Officials from APEDA (Agricultural and Processed Food Products Export Development Authority) had reported that the demand for Indian organic food products is on constant increase worldwide, as India exported organic products worth $515 million in financial year 2017-18 (Business Standard, 2018). Besides transfer and store of energy, phosphorus (P) enables a plant to promote root, flower and fruit development, and allows early maturity. Organic P in soils serves as an important source of P for plant growth, as most of the P (50-80%) is found in the organic form such as inositol phosphate, phytate, nucleic acids, etc. under organic production system. Being a major plant nutrient, P is vital for plant life. However, the problem in acidic soil is that plants face major deficiency of P, as it remains unavailable due to high fixation by the dominant Fe/Al oxides and hydroxides.

The conventional soil test protocols for phosphorus (P) do not take into account the potentially available inorganic P pools under organic production system. Inorganic P is a very important contributor as far as plant P nutrition is concerned (Saha and Mandal, 2011). Due to the lack of an appropriate soil-testing based management strategy of nutrients in organic farms, the farmers apply the organic manures based on their Indigenous knowledge, which results in nutrient imbalance due to progressively declining residual nutrients in the soil leading to low yield and poor-quality produce (Saha and Mandal, 2011). The knowledge of the status of these nutrients in the soil and their requirement by crops is very important in a bid to recommend appropriate amount of the organic inputs to be added in order to maintain higher productivity and high quality of produce. The conventional inorganic P extractant used for extracting the phosphorus in acidic farms is the ‘Bray 1’ extractant. It is not likely to be equally efficient in extracting the potentially available P or the insoluble inorganic phosphorus pools in organic farming system. It means that the dynamic fraction of P, which is
applied in conventional soil testing, cannot help measure the correct status of phosphorus in soils under organic production systems (Saha and Mandal, 2011).

Thus, through applying the conventional methods of P extraction, one cannot know exactly the amount of P, which is available in an organic farm. Hence, a different and suitable extractant that can extract such potentially available P in acidic soils under organic production system is highly required to develop proper and efficient recommendation of phosphorus doses necessary to attain the expected yields. Therefore, the objective of this research is to find out the most suitable organic acid extractants which can give us the appropriate results of potentially available P in acidic soils of organic farms.

**Study Area**

The North-Eastern Region (NER) of India and other hilly or mountainous areas, where a lot of biomass is available from forest, weeds, crops, etc., organic farming would be economical. Moreover, organic produces are expected to fetch premium price (at least 25%) and, therefore, should be economical to poor farmers.

The NER of India is mostly mountainous and covers around 26.2 million hectares of land and around 8 percent of the country’s land mass. North-East mountain region in India is blessed with the highest amount of rainfall as compared to the other parts of the country. However, due to high rainfall and the hilly or mountainous regions in most of the parts of North-East India, soil erosion is quite common, which, in turn, leads to severe decline in soil fertility, biomass carbon, organic matter, etc. The phenomenon of soil erosion in such mountainous regions also leads to $\text{Al}^{3+}$ toxicity (high soil acidity) and exposure of compact sub-soil of poor physiological properties. Among others, the state Meghalaya is mainly covered with hills, valleys and mountains in almost the entire state except in some pockets. Terrace and contour farming in the mountains can be seen most popular amongst the farmers. The undulating topography of the mountains makes it difficult for the farmers to go for conventional farming system with the application of chemical fertilizers through standard recommended process, leaving them with no choice except following the Indigenous and organic farming system. Apart from difficulties in supplying the required chemical fertilizers and pesticides for the conventional farming due to hilly and mountainous terrains, the farmers here are unaware of Green Revolution and, hence, the farming is by default organic in nature.

Meghalaya is one of the promising states of NER of India as far as the organic farming potential is concerned. Hills or mountains restrict the farm modernization of the region and, hence, farmers are mostly found to practice the traditional or Indigenous farming system having organic base as against the conventional practice requiring supply of chemical inputs. Like other states of the NER, Meghalaya is mountainous and by default organic, and the farmers of this state are mainly organic producers (Mandal *et al.*, 2006). The farmers here use very low levels of chemical fertilizers and pesticides and the nutrient conversion is highly influenced by various residues from livestock and the available forest biomass. As reported in The Telegraph (2020), 1,410 hectares of agricultural land have been certified for organic farming in the state. Focus has been put on developing the identified organic farms or areas of the state into certified ones.
Various important crops like ginger, turmeric, pineapple, cashew, orange, vegetables, tea plantation, etc. are organically grown in different areas of Meghalaya.

**Organic Farming**

Organic agriculture is a production system which avoids or largely excludes the use of synthetic compounded fertilizers, pesticides, growth regulators and livestock feed additives (Lampkin, 1990). To the maximum extent feasible, organic farming system relies on crop rotations, crop residues, animal manures, legumes, green manures, off-farming organic wastes and biological pest control to maintain soil productivity, to supply plant nutrients, and to control insects, weeds and other pests. It was considered that organic farming might solve all the problems of weeds, insects and pests, and is still considered as one of the best options for protecting/sustaining soil health. It gained a lot of importance in present day agriculture. It is conceptualized as the approach of farming geared to increase the production and productivity with the use of organic manures and natural methods of plant protection instead of using synthetic fertilizers and pesticides. Along with that, it aims for sustainability by not disturbing the ecological balance, thereby, sustaining soil life and beneficial interactions.

Organic manure contains numerous macro- and micro-nutrients. It is capable of supplying every nutrient to the extent that can be assimilated by plants. Organic manure, being a complex mixture, is a storehouse of nutrients. It releases nutrients gradually so that all nutrients are supplied over a longtime in right proportions (Swami, Singh and Patgiri, 2022). Its compounds are subjected to minimal loss by leaching. The colloidal product of decomposition of organic manure has a high ‘base exchange’ capacity, which means the exchanged ions are not flushed out and the contact between plant root hairs and the organic manure particles is ensured. Thus, there is a built-in economy of supply and demand. Due to actions of various microbes, earthworms and other factors, the organic matter is continually reverting to inorganic state to make mineral salts such as compounds of phosphorus, potassium, calcium, magnesium, sodium, iron, manganese, zinc, copper, boron, etc. available for plants (Swami *et al.*, 2021). Due to various difficulties of carrying large and massive machineries and inputs used in conventional agriculture, farmers in mountainous regions of Meghalaya rely mostly on organic farming.

**Organic Farming in the NER of India**

NER of India is essentially an organic region with almost every NE state practicing organic farming.

- The inorganic chemicals and agro-chemicals are not preferred by the farmers both in planes and in hills.
- In almost every household, farmers are maintaining livestock (pig, poultry, cattle, goats, etc.) producing sufficient quantity of on-farm manures.
- NER of India receives higher amount of rainfall leading to profuse production of biomass including weeds, shrubs and herbs which can be used for self-sufficiency.
- This region has a potential of about 47 million tons of producing organic manure including 37 million tons from animal excreta and 9 million tons from crop residues (Munda *et al.*, 2014).
Crops like rice, wheat, maize, pulses, oilseeds, fruits and vegetables are grown organically in the fully organic NE state of India, Sikkim.

Turmeric, ginger, black pepper, cardamom, pineapple, etc. are grown organically in Meghalaya.

Various other products like arecanut, ginger, passion fruit, vegetables, various cereals, pulses, oilseeds, etc. are grown organically in Assam, Manipur, Mizoram, Arunachal Pradesh, Nagaland, Tripura of NE India.

Importance of Phosphorus and its Availability in Organic Farms

Among others, phosphorus (P) plays a very important role in growth and development of plants. Its contribution towards energy storage and transfer, root development, photosynthesis, respiration, signal transduction, nutrient movement, and transfer of the genetic characters within the plant system prove it to be vital for the life of a plant (Malhotra, Sharma and Pandey, 2018). It is also a major structural component of phosphoproteins, phospholipids, coenzymes, sugar phosphates and enzymes. Cell division and development, root development, bringing early maturity, contribution towards nitrogen fixation process, flower and seed formation, improving drought and salinity resistance, enhancing disease resistance, and alike are some other significant roles played by phosphorus. Hence, it is claimed to be one of the most essential macronutrients in a plant system. However, this essential nutrient remains significantly deficient in high rainfall zones of tropical and subtropical mountainous regions mainly due to fixation and precipitation of the phosphate ions underlying iron and aluminium oxides and hydroxides that are dominant in such acidic mountains (Nanganoa and Njukeng, 2018). The P concentration in soil solution is significantly low having the range of 0.003 ppm to 3 ppm P (average ~0.05 ppm) whereas the average quantity of P needed by plants is 0.3 to 0.5 kg P/ha/day (Tisdale et al., 2013). Hence, proper replenishment of the solution P is required to meet the plant P requirement and the chemical phosphatic fertilizers serve this purpose. However, the overuse of these chemical fertilizers leads to imbalance of micronutrients as well as the microbial functions of the soil. Hence, a drift towards organic farming can be justified.

Besides the solution P pool, the organic as well as insoluble inorganic P pools are quite significant as far as the phosphorus nutrition of the plants is concerned because both these pools contribute quite a high amount of available phosphorus for plant uptake through mineralization processes. More than 50% of the total P is contributed by organic P with the range varying from 15 to 80 percent (Tisdale et al., 2013). Inositol phosphate, phospholipids, nucleic acids, nucleotides and sugar phosphates are the important organic pools of P out of which the inositol phosphate (>35%), phospholipids (1-5%) and nucleic acids (0.2-2.4%) are the major contributors of the organic P (Das, 1996). The most common phosphate ester, inositol hexaphosphate, contributes around 50% of total soil organic P.

Around 95% soils of the North Eastern Mountain region of India are acidic, out of which around 65 percent soils come under strong acidic range with less than 5.5 pH. Meghalaya is no exception. Out of the 21 million hectares (m ha) acidic soils of North Eastern Mountain region of India, 2.24 m ha soil covers Meghalaya (Singh and Sanjay-Swami, 2020). These soils can be seen deficient in phosphorus mainly due to leaching of bases from up above the mountains through high rainfall water that result into
dominance of iron and aluminium oxides facilitating fixation of phosphate. Therefore, systematic study and access to the organic P pool in acidic soils, particularly for phosphorus nutrition, have its paramount importance.

The mineralization of the organic P and the insoluble inorganic P present in the soil is mainly catalyzed by the enzymes and organic acids released by various soil microorganisms, plant roots and decomposing organic matters. Several of the released organic acids have the ability to bond with Al, Fe, Ca, Mg, Mn, and Zn by way of ion-exchange, surface adsorption, coagulation and peptization reactions; therefore, they play an important role in the mobilization of such metals in soil-water systems. These complex reactions may lead to the release of P from P-bearing minerals (Kpomblekou-Ademawou, 1993). Hence, for extracting or estimating these potentially available pools of P under organic farming, generally, the organic acids are recommended. Therefore, the research work is based on identifying the best suitable organic acid extractant for acidic mountainous soils of Meghalaya under organic production system. By knowing the amount of potentially available P in an organic farm using the suitable extractant, which can extract the accurate amount of that P in such type of soils, a proper recommendation for P can be prescribed.

Keeping the above facts in view, an investigation was carried out with the following objective: Identification of the suitable organic acid extractants to extract the potentially available insoluble inorganic P pools in acidic soils under organic farming system.

**Methodology**

Different organic acid extractants are used to extract the potentially available phosphorus under organic production system, which is a very important fraction of phosphorus for plant availability in organic farming. This fraction is not appreciated through conventional method of extraction by Bray-1 extractant. P extraction is affected by the choice of organic acid (Gerke, Beißner, and Römer, 2000), extraction pH, extraction time (Turner, 2008) and solution to soil ratio (Chapman, Edwards, and Shand, 1997).

Meghalaya is predominantly mountainous and geographically known as “Meghalaya Plateau”. The present investigation was conducted at five different sites of Ri-Bhoi district of Meghalaya representing two farming systems i.e., conventional and organic farming systems. The five selected sites are: 1) College of Post Graduate Studies in Agricultural Sciences (CPGS-AS) research farm, Central Agricultural University (CAU-I), Umiam, 2) Palwi village of Bhoirymbong block, 3) ICAR research farm, Umiam, 4) CPGS-AS, Krydemkulai and the 5) Krydem village of Bhoirymbong block. The first two sites were conventionally managed, while the later three were organically managed. The soil samples were collected from the selected sites and were then analyzed and extracted in the laboratory with five different organic acid extractants along with a check extractant (Bray-1) to estimate the potentially available phosphorus. The organic acid extractants used for analysis of potentially available phosphorus are citric acid, double lactate, 2-keto-glutaric acid, acetic acid and lactic acid extractant. The analysis was done following the standard protocols. The composition of the extractants and the standard protocols of the analysis are referenced in table 1. One
conventional P testing extractant Bray-1 extractant was used as the check extractant. The strength of extraction is highly dependent on the structural and functional properties of the organic acid extractants which vary in chelation properties.

Thereafter, multiple linear regressions were performed taking total P as dependent variable to adjudge the best suitable extractants in organic acidic soils. The soils of the research farm of CPGS-AS, Umiam, research farm of ICAR, Umiam and the virgin forest soil farm of CPGS-AS, Krydemkulai were of dominantly Inceptisols (USDA Taxonomy) and the soils of the farm of Palwi village and Krydem village of Bhoirymbong block were of Alfisols. Soils were mostly light to medium textured (sandy loam and clay loam) with depth ranging from deep to very deep. Soils of the study area were found to be acidic (pH below 5.5). Chemical composition of the different types of soils existing in Meghalaya is illustrated in table 1.

Table 1: Organic acid extractants employed to extract the potentially available inorganic phosphorus

<table>
<thead>
<tr>
<th>S. N.</th>
<th>Extractant</th>
<th>Composition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Acetic acid extractant</td>
<td>0.54 N Acetic acid + 0.7 N Sodium acetate at pH 4.8</td>
<td>Morgan, 1941</td>
</tr>
<tr>
<td>2.</td>
<td>Lactic acid extractant</td>
<td>0.02 M Ca-lactate + 0.02 M HCl at pH 3.7</td>
<td>Egner and Riehm, 1955; Egner et al., 1960</td>
</tr>
<tr>
<td>3.</td>
<td>Citric acid extractant</td>
<td>2% Citric acid</td>
<td>Blazer and Blazer-Graf, 1984</td>
</tr>
<tr>
<td>4.</td>
<td>Double lactate extractant</td>
<td>0.02 M Ca-lactate + 0.05 M Lactic acid at pH 4.1</td>
<td>Dey et al., 2019; Riehm, 1943</td>
</tr>
<tr>
<td>5.</td>
<td>2, keto-glutaric acid extractant</td>
<td>0.05 M 2, keto-glutaric acid+0.02 M HCl at pH 4.0</td>
<td>Dey et al., 2019</td>
</tr>
<tr>
<td>6.</td>
<td>Bray 1 extractant (Check extractant)</td>
<td>0.03 N NH₄F + 0.025 N HCl</td>
<td>Bray and Kurtz, 1945</td>
</tr>
</tbody>
</table>

**Result & Discussions**

**Details of the Existing Soil’s Chemical Characteristics in the Study Area**

As analyzed in the laboratory, the pH, soil organic carbon (SOC) (%), available P (kg/ha) and total P (kg/ha) of the sampling sites are presented in table 2.

As reported in table 2, the pH of all the studied organic soils was higher than that of the conventional soils. The lowest pH was found to be in the soil of conventional Palwi village, Bhoirymbong (4.58) followed by the soil of conventional CPGS-AS farm, Umiam (4.70). The pH of the organic soil of ICAR farm, Umiam, Krydem village, Bhoirymbong and CPGS-AS farm, Krydemkulai were found to be 4.91, 4.94 and 5.15, respectively. The higher pH of the organic soils might be due to the buffered status of soil under organic farming system than that of the conventional system.
Soil organic carbon (SOC, %) was resulted higher in the soils of organic farming system than that of the soils under conventional farming system. The highest value of 2.53% of SOC was evident in CPGS-AS farm, Krydemkulai. The other two organic sites viz. ICAR farm, Umiam and Krydem village, Bhoirymbong resulted SOC to be 1.81% and 1.65%, respectively. Conventional farming sites resulted lower SOC of 1.13% and 1.20% in CPGS-AS farm, Umiam and Palwi village of Bhoirymbong, respectively. The higher values of SOC in the organic soils might be due to continuous addition of organic manures in such soils and lesser decomposition of the organic matter. On the other hand, lower values under conventional soils might be due to non-addition of organic manures and only usage of chemical fertilizers (table 2).

Available P was found to be very low under conventional farming systems, especially in Palwi village of Bhoirymbong (1.11 kg/ha) whereas the value of the other site was found to be at par with all the 3 sites under organic farming system. ICAR farm, Umiam, Krydem village, Bhoirymbong and CPGS-AS farm, Krydemkulai sites had the values of 16.07, 18.37 and 17.25 kg/ha of available P, respectively. The low value of available P might be due to extreme fixation of P by iron/aluminium oxides and hydroxides dominant in acidic soils (table 2).

Total P was higher in organic soils than that of the conventional soils. Highest total P was reported in the ICAR farm, Umiam (1933.35 kg/ha) followed by Krydem village, Bhoirymbong (1748.18 kg/ha) and CPGS-AS farm, Krydemkulai (1645.67 kg/ha). The values in the conventional soils were quite low with 1321.58 kg/ha and 1542.12 kg/ha in the CPGS-AS farm, Umiam and Palwi village, Bhoirymbong, respectively. The higher values of total P might be because of the organic and other fractions of P which were not considered in available P estimation (table 2).

The results obtained are summarized in the following table 3. As depicted in table 3, the extractable P pools extracted by the organic acids were relatively higher in size under organic farming system as compared to the conventional system. Acetic acid, being a monobasic acid with one carboxyl functional group, triggered lesser extent of chelation of the predominant iron and aluminium ions as compared to the other extractants. So, this
pool could contribute lesser towards P nutrition. The lowest value of 3.52 kg/ha was evident in the conventional Palwi village and the highest value of 6.827 kg/ha was evident in the organic site of Krydemkulai under the acetic acid extractable pool.

Table 3: Acetic acid, citric acid, lactic acid, double lactate and 2-ketoglutaric acid soluble P$_2$O$_5$ of different sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Status</th>
<th>Acet acid soluble P$_2$O$_5$ (kg/ha)</th>
<th>Citric acid soluble P$_2$O$_5$ (kg/ha)</th>
<th>Lactic acid soluble P$_2$O$_5$ (kg/ha)</th>
<th>Double lactate soluble P$_2$O$_5$ (kg/ha)</th>
<th>2-ketoglutaric acid soluble P$_2$O$_5$ (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPGS-AS</td>
<td>Conventional</td>
<td>4.227±0.41b</td>
<td>12.220±0.90d</td>
<td>18.790±0.75a</td>
<td>33.180±1.00c</td>
<td>29.631±1.06c</td>
</tr>
<tr>
<td>Palwi</td>
<td>Conventional</td>
<td>3.520±0.41b</td>
<td>5.630±0.46e</td>
<td>17.983±0.68ab</td>
<td>27.137±1.06d</td>
<td>25.257±1.00c</td>
</tr>
<tr>
<td>ICAR</td>
<td>Organic</td>
<td>6.427±0.37a</td>
<td>45.365±0.75a</td>
<td>16.340±1.00abc</td>
<td>47.590±1.03a</td>
<td>60.413±1.06b</td>
</tr>
<tr>
<td>Krydem</td>
<td>Organic</td>
<td>6.599±0.29a</td>
<td>32.231±0.90b</td>
<td>14.990±0.60c</td>
<td>43.736±1.29ab</td>
<td>63.344±1.49ab</td>
</tr>
<tr>
<td>Krydemkulai</td>
<td>Organic</td>
<td>6.827±0.63a</td>
<td>24.027±1.28c</td>
<td>15.693±0.62bc</td>
<td>42.517±1.28b</td>
<td>68.120±1.71a</td>
</tr>
</tbody>
</table>

A significant contributable size solubilized by citric acid was reported by scientists, as it is an alpha-hydroxy derivative of tribasic acid with three carboxyl and one hydroxyl functional groups (Gour, 1990; Drouillon and Merckx, 2003). The sizes of this pool were much higher under organic sites than that of the conventional sites. Under this study, highest value of 45.365 kg/ha P$_2$O$_5$ is obtained in the organic soils of ICAR and the lowest value of 5.63 kg/ha is obtained in the soils of Palwi village, which is conventionally managed (Table 3).

The contribution of lactic acid extractable P pool was routinely found to be relatively lower. However, it is higher than acetic acid extractable P pool observed in this study, because of the presence of a carboxyl and a hydroxyl functional group facilitating greater chelation property. The unique observation of this pool is that this particular extractant could extract the potentially available phosphorus almost equally under both conventional and organic farming system.

Bigger sizes of double lactate soluble P$_2$O$_5$ is reported in organically managed soils compared to the conventional soils because of the formation of highly buffered extractant. Much higher values within organic sites are observed than that of the conventional sites. Values of 47.59 kg/ha, 43.736 kg/ha and 42.517 kg/ha P$_2$O$_5$ are recorded in the organic sites of ICAR, Krydem village and Krydemkulai, respectively. Values of 33.18 kg/ha and 27.137 kg/ha P$_2$O$_5$ were recorded in the conventional sites of CPGS-AS and Palwi village, respectively (Table 3). 2-ketoglutaric acid extractable P pool is reported to be the highest contributing pool. The presence of a keto group and two carboxyl groups in 2-ketoglutaric acid contributed excellent sizes of P$_2$O$_5$ extracted. This pool also contributed more in organic soils compared to the conventional soils. Enormous values of 60.413 kg/ha, 63.344 kg/ha and 68.12 kg/ha are reported at the organic sites of ICAR, Krydem village and Krydemkulai, respectively. On the other hand, values of 29.631 kg/ha and 25.257 kg/ha are reported at the conventional sites of CPGS-AS and Palwi village, respectively (Table 3).

Using the data in table 3, regression equations are generated by performing multiple linear regression taking ‘Total P’ as the dependent variable and organic carbon (OC%) and organic acid extractable P$_2$O$_5$ as the independent variables. All the organic acid
extractants, singly and in combination, are considered; and many regression equations with respective $R^2$ values are derived for both single and combination extractants (Table 3). The results of the regression equations (single) suggest that the highest $R^2$ values is evident for citric acid extractant ($R^2=0.78$) followed by double lactate extractant ($R^2=0.62$). Similarly, the results of the combination extractants regression equation suggest that the best combination of extractants is the citric acid and double lactate extractants with $R^2$ value of 0.93. On the other hand, extremely low value of $R^2$ is obtained with conventional Bray-1 extractant ($R^2=0.26$). This suggests that the variability of total P in the soils can be best explained by the citric acid extractant and double lactate extractant while very low degree of variability of total P can be explained by Bray-1 extractant. Total P is taken as the dependent variable because the suggestions of organic manure doses in an organic production system are made based of the values of total P of the particular organic site. The results along with the generated $R^2$ values are presented in the table 4.

Table 4: Regression equations taking Total P as the dependent variable along with the generated $R^2$ values

<table>
<thead>
<tr>
<th>S. N.</th>
<th>Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Total P= 1289.18 + 36.77 OC% + 12.05 (Citric acid-P)</td>
<td>0.78</td>
</tr>
<tr>
<td>2.</td>
<td>Total P= 804.18 – 19.70 OC% + 22.32 (Double lactate-P)</td>
<td>0.62</td>
</tr>
<tr>
<td>3.</td>
<td>Total P= 1283.70 + 203.10 OC% + 1 (Bray-1 P)</td>
<td>0.26</td>
</tr>
<tr>
<td>4.</td>
<td>Total P= 2566.36 + 268.41 OC% + 37.75 (Citric acid-P) – 58.63 (Double lactate-P)</td>
<td>0.93</td>
</tr>
</tbody>
</table>

**Conclusion**

Five different organic acid extractants are chosen to determine the best extractant that can extract the potentially available P under organic farming system. Multiple linear regression is performed taking total P as dependent variable with all the extractants and organic carbon. All the possible combination of extractants are considered and the results have proved that a very poor relationship is evident between organic carbon and Bray-1 soluble P (considered as check) having $R^2$ value of 0.26. Among the organic acid extractants, citric acid followed by double lactate are found to be best in defining the highest amount of variation of total P in organic soils bearing $R^2$ value 0.78 and 0.62, respectively. The combination regression reveals that both citric acid and double lactate extractants are strong enough to define the variation of total P in organic farming system with highest $R^2$ value of 0.93.

Based on the results of the present investigation, it may be concluded that the highest $R^2$ value i.e., 0.93 for citric acid and double lactate extractant, defines the highest variation of total P in an organic production system. The $R^2$ values of all other regression equations are lesser. The value for conventional Bray-1 extractant is very small i.e., 0.26. Hence, the famers of Meghalaya, particularly of Ri-Bhoi district, may be advised to get tested their soils for potentially available phosphorus through citric acid and double lactate extractants in an organic production system; and, accordingly, they can apply P doses from organic nutrient sources that not only restore soil health but also ensure a successful organic cultivation.
References


Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Author 1</th>
<th>Author 2</th>
<th>Author 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceived and designed the research or analysis</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Collected the data</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Contributed to data analysis &amp; interpretation</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Wrote the article/paper</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Critical revision of the article/paper</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Editing of the article/paper</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Supervision</td>
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<tr>
<td>Project Administration</td>
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<tr>
<td>Funding Acquisition</td>
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<tr>
<td>Overall Contribution Proportion (%)</td>
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<td>30</td>
<td>20</td>
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</table>

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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To see original copy of these declarations signed by Corresponding/First Author (on behalf of other co-authors too), please download associated zip folder [Declarations] from the published Abstract page accessible through and linked with the DOI: https://doi.org/10.33002/nr2581.6853.070104.
Tourism and Recreational Industry for Rural Development in Ukrainian Mountains

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Abstract

This article addresses how to develop national and local policy on tourism and recreation in mountainous rural areas considering the recreational capacity, demographic patterns and economic situations, with an emphasis on local livelihoods. Management of recreational natural resources is an integral component of the national environmental policy. It is considered that the recreational natural resources management is broader than the recreational industry management, since the former covers protection and restoration of the resources. The multiplier economic effect and joint use of recreational resources by various users are the key issues for the industry. Evidently, almost in all the Ukraine’s regions, accessible recreational resources are not used efficiently enough. In order to evolve an appropriate sustainable tourism policy, a multilevel algorithm is developed on how to classify areas depending on the recreational resources and tourism industry. The algorithm supplies several policy models of the recreational industry’s development, taking into account the types of settlements (urban, rural, intermediate, and mountainous), proximity of settlements to urban centres (urbanized and peripheral), recreational capacity of areas (high, medium, low), and economic efficiency of local recreational industry (productive, semi-productive, unproductive). Accordingly, three types of communities’ development strategies have been suggested. They include the recreational focus, profound recreational industry, and recreations for locals. The novelty of this research is that it presents the approach on how to assess the capacity of local recreational resources and the industry. The multilevel algorithm is proposed to classify areas and define better approaches for the local policies.

Keywords

Recreational natural resources; Recreation-and-tourism industry; Recreational capacity; Mountainous area; Algorithm

Introduction

Recreational resources include spa, sanatorium, resort services and many more. Tourism and recreation industry is important for the national economy and is applauded in many national, regional and local policy documents. Collins-Kreiner and Rem (2021) consider
current national tourism strategies, and Nientied and Toto (2020) study new tourism policy for urban spaces. In the developing countries, researchers pay more attention on tourism governance (Siakwah, Musavengane and Leonard, 2020), tourism administration (Ndivo and Okech, 2020), and tourism regulation (Charles, 2019). Community-based tourism and its impact on communities’ welfare and life standards are in the focus all over the world, such as in Lesotho (Thetsane, 2019), Columbia (Yanes et al., 2019) and Pakistan (Khalid et al., 2019).

Ministry of Ecology and Natural Resources of Ukraine is responsible for protection, conservation and judicious use of the recreational resources. Recreation and tourism industry is important for many countries, especially those having mountain areas. Typically, local strategies on how to use recreational resources do not match carefully with the resource capacity, facilities, personnel and the supplying industries. Particularly, it is true for mountain regions like Carpathians. The current unregulated mass tourism practices result either into the under-use of the recreation resources or, contrarily, its depletion. If local people disregard recreational capacities of the environment, tourist and recreational resources deplete and people get less income.

With it, it is argued that a local policy on natural recreational resources usage has to be developed within given challenges. The approach is to match the resource usage practices with the industry’s capacities and facilities. The better policy has to facilitate the supply of recreational services and balance the resource usage in order to preserve the resources for future generations, save the environment and help locals to gain timely income, at least. This position is even more important for the Carpathian mountainous region. Consequently, the aim of the study is to classify areas depending on several geographic, demographic and economic variables in order to develop schemes of the policies that will provide a better life for the communities.

**Review of Literature**

Studies on the sustainable use of recreational natural resources are mostly interdisciplinary. Undertaken by academicians, such studies elaborate theory and methods to systematize and evaluate recreational resources and practice of its usage. Rutynsky and Zinko (2006) developed the theory of recreational natural resource use and drawn maps of the resource allocation outlining the structure. Rudenko, Vatseba and Solovey (2001) defined what the natural and recreational capacities of areas are. Matsola (1997) evaluated economic effects of recreational and tourism industry. Beidyk (2001) looked into approaches to managing natural recreational resources, and studied various types of recreational activities. Cherchyk and Mostenets (2016), Bernini and Cracolici (2015), and Massidda and Etzo (2012) studied how to protect and develop natural recreational resources sustainably. Yakovenko and Tahan (2009) studied the nature management and differentiated it by area types, and Bezugly (2014) developed the relevant strategies.

Some scholars have developed conceptual frameworks of spatial landscape and forest planning for recreation. Usually the size, distribution, shape, adjacency, connectivity, and proximity are the values to be assessed if spatial configuration of recreational areas is taken into consideration (Baskent and Keles, 2005). Other authors add one more value, which is the environmentally responsible behavior of tourists and vacationers (Lee et al.,
Charnley (2006) soundly notes in order to improve nature management that decision makers should ensure that natural-resource management policies are socially acceptable. In this regard, social and economic strategies should be based on accurate assumptions about the relations between the resources being managed and well-being of local communities.

With the structural analysis some authors have composed recreational resources, defining recreational activities, and assessing the industry’s current status (Abbas and Sagsan, 2019). With mathematical approach, recreational capacities of communities’ areas are assessed, along with the estimate indices of its social and ecological status (Suarez et al., 2020). At the same time, there are no approaches to segregate recreational resource usage depending on economic, demographic, and geographical status of areas. The issue is important for Ukraine in the context of the administrative and territorial reform, which gives territorial communities more opportunities to use and manage the natural resources.

**Methodology**

In this article, structural analysis is applied to define what natural recreational resources are and depict its position in the nature management system, considering its functions, key factors and impacts. Tourist and recreational capacities of rural areas are estimated by the index method. Relevant statistical data is processed further to provide a comparative assessment of the economic efficiency of the recreation industry. Graph and synthetic methods are applied to depict the multilevel algorithm, which classifies areas depending on its tourism and recreation capacities and spatial economic, demographic, and geographical status. Here the graph method’s application is close to approaches to developing empirical models in tourism landscape planning (Siroosi, Heshmati and Salammahiny, 2020)\(^1\). The synthetic method is particularly applied to combine, integrate, and synthesize research findings in an advanced manner (Schick-Makaroff et al., 2016). Consequently, in this research, spatial and recreational comprehensive differentiations of areas were synthesized to elaborate a unique classification of the areas depending on the recreational industry’s status and the policy. Finally, the policy development method was applied to supply regional and local strategies for the recreation and tourism industry. Usually, policy development includes the following steps: identification of the problem, elaboration, and adaptation of the document (law, decree, plan, or program), policy implementation, and evaluation.

The primary goal of this study is to classify areas depending on the ways of recreational natural resource usage in order to develop policies providing better economic and social outcomes. Firstly, it is defined what the recreational natural resources are with its components. Secondly, recreational and tourism capacities of communities’ areas were assessed. Thirdly, the areas were classified accordingly and schemes of the recreational natural resource usage are suggested. Finally, regional and local strategies of the recreation and tourism industry’s development have been proposed.

Moreover, a comprehensive assessment of the recreational industry by regions is performed in the following manner:

---

\(^1\) For more information, please see https://t.ly/Q3aD2
1. Key dimensions of tourist and recreational capacities are identified.
2. Indicators relevant to the identified dimensions are selected.
3. Required database is defined, and the raw data is processed.
4. Specific, group, and aggregated indices are calculated.
5. The regions are divided into four groups according to the aggregated indices' scores.

Authors have modified comprehensive approach of Rudenko, Vatseba and Solovey (2001) who assessed natural and recreational potential (aka the capacity) depending on recreational zones, supplied services, natural reserves and facilities for extraction of mineral waters and mud. Consequently, four dimensions (values) of the tourist and recreational capacities were defined. The dimensions were 1) natural resources and ecological status of the areas, 2) the facilities and logistics, 3) economic efficiency of the industry, and 4) social efficiency of the industry. In the framework of the listed four dimensions, key indicators (variables) for the tourism industry’s assessment were identified and related to its assets, as mentioned in table 1. The structure of the integral estimation of the tourism-and-recreation industry of Ukraine’s regions is developed considering the research goal and based on earlier elaborations (for example, Pelishenko, 2015). State Statistical Service of Ukraine (2020) databases were consulted to find necessary data for the regions of Ukraine. Statistical exploratory analysis facilitated classifying the regions with indicators relevant to the recreation industry’s efficiency (He et al., 2019). Variables, which are listed in table 1, have been processed with formulas 1-4, and relevant indices have been calculated with EXCEL tools. Particularly, specific indices were calculated with formulas 1 and 2, group indices – with formula 3, and aggregated indices – with formula 4 (Shubaly, 2011).

Table 1: Structure of the integral estimation of the tourism-and-recreation industry of Ukraine’s regions

<table>
<thead>
<tr>
<th>Values</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural resources and the environment</td>
<td>Relative monetary value of natural recreational resources, USD per sq. km</td>
</tr>
<tr>
<td></td>
<td>Emissions, tons per sq. km</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Spa and resort centers, units per sq. km</td>
</tr>
<tr>
<td></td>
<td>Tourist and recreation camps for kids, units per sq. km</td>
</tr>
<tr>
<td></td>
<td>Hotels, number of beds per sq. km</td>
</tr>
<tr>
<td>Economic efficiency</td>
<td>Recreants, persons per unit place in spa and resort centers</td>
</tr>
<tr>
<td></td>
<td>Kids migration for recreation, %</td>
</tr>
<tr>
<td></td>
<td>Hotels capacities used, %</td>
</tr>
<tr>
<td></td>
<td>Tourists to population ratio, %</td>
</tr>
<tr>
<td>Social efficiency</td>
<td>Employees in spa and resort centers to population ratio, %</td>
</tr>
<tr>
<td></td>
<td>Vulnerable kids to all kids in spa and resort centers ratio, %</td>
</tr>
</tbody>
</table>

For the listed variables in table 1, specific indices were calculated with the following formulae:

\[ Y_{ij}^k = \frac{x_{ij}^k}{x_{jmax}^k}, \tag{1} \]

where \( X \) – a variable for \( i \)-region \((i = 1, m; m = 25)\);
\( j \) – number of a variable in a value’s set \((j = 1, n; n = 4)\);
\( k \) – number of a value’s set \((k = 1, p; p = 4)\).

Indices calculated within the above-presented formula vary from 0 to 1, where 0 means the worst and 1 means the best scores of natural recreational resources in a region. Remarkably, for the emissions variable, the index is calculated with another formula:

\[
Y_{ij}^k = \frac{x_{ij}^{k \text{min}}}{x_{ij}^k} .
\]  

(2)

Next, the specific indices were integrated in order to calculate complex scores for the natural and recreational industry of the regions, by applying following formula:

\[
Y_i^k = \sqrt{\prod_{j=1}^{n} (1 + Y_{ij}^k)} - 1 .
\]  

(3)

\[
Y_i = \sqrt[\beta]{\prod_{k=1}^{p} (1 + Y_i^k)} - 1 .
\]  

(4)

The results of the calculations are presented in table 2, where the regions are divided into groups according to the aggregated indices’ scores.

**Results**

Recreational natural resources management is a component of the system of nature management. The nature management system reflects the interactions of a society with the environment and is specified by the current socio-ecological paradigm, mainly known as the sustainable development concept (Figure 1).

Recreational activities mean supply of recreational services where required natural and industrial resources are located outside the permanent settlements of vacationers. The ‘recreational natural resources use’ is a broader term as it additionally embraces exploration of new recreational zones and resources, builds the recreational environment, and provides environmental protection, renovation, and the rational use. If these tasks are accomplished, the recreational resource management is considered to be rational. The recreational resources management is sustainable if it concurrently takes into account social and economic needs of people and constraints of the environment. Key challenge for the sustainable recreational natural resources management is to match growing demand for recreational services with the goal to preserve recreational resources and valuable historical and cultural sites.

Recreational resources have some specifics. Firstly, recreational resources cannot be separated from the environment or extracted. Secondly, they define range and types of recreational activities. Thirdly, the resources are multifunctional since they provide various health and recreation services. Fourthly, the economic effect is multiple if the resources are used in full (Eugenio-Martin and Campos-Soria, 2014). Fifthly, the recreational resource use can be coordinated with other fields of nature management. Sixth, the recreation becomes a priority industry if natural recreational resources are not used differently. Economic, social and environmental impact of recreational natural resources relates to its ability to catalyse economic growth and incomes, adds to employment of people who supply recreational and related services, and establishes a
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causal relationship between revenues of recreational entrepreneurs and quality of the environment (Job and Passler, 2013). Some scholars believe that outdoor recreation and nature-based tourism have the potential to contribute to sustainable lives, communities, and conservation and diverse local economies (Winter et al., 2020).

Recreational and tourism capacity of an area is determined by a set of available, site-specific natural, socio-economic, historical and cultural resources. Thus, the resources are a prerequisite of production and supply of recreational and tourist services. Usually, there is some gap between the resources capacity and the efficiency of their use. Sustainability of the recreational and tourism industry means that the resources are used in most appropriate/responsible way, and the recreational policy takes into account the social needs and economic benefits, without degrading the cultural assets. Consequently, recreational resources consist of areas and facilities where vacationers restore their health, recover and rest.

Usually the resources differ in contexts of natural (climate, land, water, landscape, flora, fauna, natural reserves, and mountains), historical and cultural (architecture, archaeology sites) and facilities (sanatoriums, resort centres, hotels, farms, camps). Resources of the recreation-and-tourism industry include nature, cultural heritage, buildings, logistics, finances, and human. Recreational natural resources mainly are used primarily by entities that produce and supply recreational services or are engaged into their production and supply.

In Ukraine, some gap in regulation over the tourism and recreation industry exists and impedes the development of the industry. In our opinion, the policy should focus primarily on providing equal opportunities for all suppliers of the recreational and tourist services. Yakovenko and Tahan (2009) prove that many natural, demographic and economic factors cause spatial inequality in the resource use. Together with these factors and conditions, the recreational resource capacity is different for different areas. It results into different opportunities for areas if tourism and recreation industry is developed. A targeted policy is essential to address disparities and bolster local communities. The strategies should enhance recreational activities in areas experiencing high demand for services, while ensuring sustainability. Additionally, it should offer supplementary incentives in regions where the recreational industry serves as a cornerstone for the local economy.

The set of variables and indicators of the recreational capacity is concurrent with international approach (UN WTO, 2004) and includes values on the environment since it contributes to the efficiency of the recreational industry (Stupen and Andrushenko, 2016). Thus, several indicators (stimuli and counter stimuli) are pointed out that will define the local environmental policy. For example, the decision makers can decide to set ecological routes, inform locals on benefits associated with recreational status of an area, and regulate extra number of vacationers (visitors) for each tourist season. Incorporation of ecological criteria into the recreation-planning frameworks would improve the integrated land management too (Morse, Hall and Kruger, 2009).
Figure 1: Management of tourism and recreational resources the industry

Resources
- Natural reserves
- Heritage and culture sites
- Facilities

Impact
- Economic
- Social
- Ecological

Peculiarities
- Multiplicative economic effect
- Ability to work in concordance with other types of the nature use
- Priority if other industries do not use natural resources of an area

Authorities and units
- National and local bodies
- Small and medium enterprises

Functions
- Development of novel territories and resources
- Making recreational surrounding
- Protection, restoration, and use of the resources
- Environmental safety

Tourism and recreation industry

Resources
- Nature
- Facilities
- Capital
- Staff

Facilities
- Hotels
- Spa, sanatorium and resort centers
- Tourism agents
- Tourism operators
- Rural and agri-tourism seats
- Natural parks and reserves
- Mountains

Health recovery, rest, sport and culture
Classification of areas depending on recreational natural resource use and strategies of the communities’ development is presented as the algorithm (Figure 2). In Ukraine, the environment, facilities and economic efficiency of the recreational industry are quite different for urban and rural areas. Therefore, for the recreational classification, areas are divided by types of settlements. In accordance with the variables of ‘rural population share’ and ‘road availability of urban centres’, the rural, urban, intermediate and mountainous areas are distinguished. Rural areas in Ukraine occupy over 90% of the country’s geography with 52% of the total population. The rural areas, additionally, are divided into urban-like and remote, depending on variables of the population density and average road distance to cities (Figure 2). In the next step, areas are classified depending on the recreational and tourist capacity (RTC), and the efficiency of recreation-and-tourism industry (RTI). This approach helps define better policies of the recreational natural resource use for urban, rural urban-like and rural remote areas. This classification is closer to usual division of recreational landscapes and forests on urban, peri-urban and rural as classified by Pintilii (2022).

Table 2: Indices of tourism and recreation industry in Ukraine’s regions, January 2020

<table>
<thead>
<tr>
<th>Region</th>
<th>Natural resources</th>
<th>Facilities</th>
<th>Economic efficiency</th>
<th>Social efficiency</th>
<th>Total index</th>
</tr>
</thead>
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<tr>
<td>Ukraine*</td>
<td>0.249</td>
<td>0.514</td>
<td>0.472</td>
<td>0.453</td>
<td>0.417</td>
</tr>
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<td>1st group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dnipropetrovsk</td>
<td>0.201</td>
<td>0.558</td>
<td>0.224</td>
<td>0.202</td>
<td>0.288</td>
</tr>
<tr>
<td>Zhytomyrska</td>
<td>0.340</td>
<td>0.233</td>
<td>0.198</td>
<td>0.324</td>
<td>0.272</td>
</tr>
<tr>
<td>Kirovogradsk</td>
<td>0.340</td>
<td>0.212</td>
<td>0.452</td>
<td>0.288</td>
<td>0.322</td>
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<tr>
<td>Sumska</td>
<td>0.296</td>
<td>0.284</td>
<td>0.279</td>
<td>0.257</td>
<td>0.278</td>
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<tr>
<td>Ternopilska</td>
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<td>0.352</td>
<td>0.340</td>
<td>0.219</td>
<td>0.298</td>
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<td>Kharkivska</td>
<td>0.329</td>
<td>0.298</td>
<td>0.350</td>
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<td>0.302</td>
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<tr>
<td>Chernigivska</td>
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<td>0.218</td>
<td>0.268</td>
<td>0.226</td>
<td>0.273</td>
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</tr>
<tr>
<td>Vinnytska</td>
<td>0.199</td>
<td>0.220</td>
<td>0.457</td>
<td>0.501</td>
<td>0.334</td>
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<tr>
<td>Zaporizka</td>
<td>0.206</td>
<td>0.327</td>
<td>0.513</td>
<td>0.464</td>
<td>0.370</td>
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<td>Kyivska</td>
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<td>0.308</td>
<td>0.377</td>
<td>0.379</td>
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<tr>
<td>Poltavska</td>
<td>0.219</td>
<td>0.274</td>
<td>0.499</td>
<td>0.348</td>
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</tr>
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<td>Rivnenska</td>
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<td>0.277</td>
<td>0.396</td>
<td>0.541</td>
<td>0.392</td>
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<td>Khmelnytyska</td>
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<td>0.301</td>
<td>0.642</td>
<td>0.311</td>
<td>0.379</td>
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<td>0.532</td>
<td>0.348</td>
<td>0.383</td>
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<td>3rd group</td>
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<td>Volynska</td>
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<td>0.335</td>
<td>0.424</td>
<td>0.525</td>
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<td>0.626</td>
<td>0.395</td>
<td>0.401</td>
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<td>0.595</td>
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<td>Kyiv city</td>
<td>0.420</td>
<td>1.000</td>
<td>0.608</td>
<td>0.101</td>
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<td>4th group</td>
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<tr>
<td>Zakarpatska</td>
<td>0.583</td>
<td>0.667</td>
<td>0.614</td>
<td>0.548</td>
<td>0.602</td>
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<tr>
<td>Odeska</td>
<td>0.477</td>
<td>0.683</td>
<td>0.474</td>
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<td>Kehersonska</td>
<td>0.370</td>
<td>0.614</td>
<td>0.608</td>
<td>0.602</td>
<td>0.544</td>
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* Excluding temporarily occupied territories of Crimea, Sevastopol city, and parts of Donetsk and Lugansk regions.
Figure 2: Areas’ classification depending on the recreational industry’s status and the policy
For the advantageous areas, focus should be on the recreation. For moderately favourable areas, prioritize recreations in concurrency with other industries. Likewise, for disadvantageous areas, use the recreational resources for local people only. This approach is consistent with the sustainable management principles. It is to support relations between local people and businesses, and prevent conflicts between the natural resource users (e.g., manufactures and agricultural producers, local people and visitors).

With the algorithm presented in figure 2, four groups of Ukraine’s regions (Table 2) are identified depending on status and capacity of the recreation and tourism industry. The table 2 represents the four groups of regions characterized with the aggregated scores of the recreation and tourism industry, where 1 is the highest value and zero is the lowest. The first group exhibits the minimum values for the variables and is identified as associated with regions experiencing depression. The fourth one has the highest indicators and is belonging to leading regions. The second and the third groups have intermediate values and are identified as below average and above average.

The low values of the recreation and tourism industry’s capacity are obtained mostly because of poor facilities. There are low numbers of sanatoriums and health resorts in Zhytomyrska (0.052), Sumska (0.078), Ternopilska (0.101) and Chernihivska (0.088) regions, and hotels in Kirovogradaska (0.153) and Kharkivska (0.213) regions. Poor recreational natural resources are in Zhytomyrska (0.133), Kirovohradska (0.130), Sumska (0.154), and Ternopilska (0.196) regions. Air pollution is one of the environmental indicators affecting the index. Poor air is the recreation industry’s counter stimulus for Dnipropetrovska (0.046) and Luhanska regions (0.074). Because of small number of vacationers, the industry is unproductive in Zhytomyrska (0.121), Kirovohradska (0.212), Luhanska (0.152), and Ternopilska (0.193) regions. In these regions, reasons of poor indices are a few travellers and an underuse of sanatoriums, hotels and health resorts.

The highest values of the recreational and tourism industry are observed in Zakarpatska (0.602), Odeska (0.562), and Khersonska (0.544) regions. However, these regions have low values of natural and recreational resources capacities and reduced number of summer camps for children (in Khersonska 0.138 and 0.291, respectively) as well as sanatoriums and resorts (in Zakarpatska 0.370). These reasons may reduce the recreational capacity of the regions down since the situation means the available recreational resources are not used profoundly.

**Discussion**

In Ukraine, the potential of the recreation and tourism industry remains underutilized, with a relatively small number of tourists and recreational visitors. Since 2000, a consistent downward trend has been observed in both inbound tourism (decreasing by 14% annually) and domestic tourism (decreasing by 7% annually), while the number of departing tourists has been increasing by 13% each year. This indicates a declining attraction of Ukraine as a recreational and tourist destination for both foreign and local citizens. However, coastal regions and cities with rich historical, cultural, and architectural sites, such as Kyivska, Lvivska, Chernivetska, Ivano-Frankivska, and Zakarpatska regions, still show potential for the development of the recreational
industry. Notably, the latter four regions are situated in the mountainous zones of the Carpathians.

The sustainable recreational natural resources management presumes efficient use of the resources, safety provisions and better spatial planning for recreational and tourist zones. Therefore, national and regional policies have to support conservation and restoration of valuable natural recreational areas, muds, mineral waters sources and historical and cultural heritage sites. The task is to establish the network of enterprises supplying spa and resort services and develop recreation and tourism industry in rural areas. Monitoring and control over the status of recreational resources prove that inventories, records, accounting and forecasting systems should be implemented as soon as possible (Kirkova, 2014).

Ukrainian scholars have presented various strategies and tools aimed at fostering the sustainable advancement of tourism and recreation. Panchenko, Sukach and Golub (2018) advocate for the reconstruction and modernization of domestic recreational resorts in alignment with existing legislation. However, ecotourism currently lacks comprehensive national regulation and oversight, highlighting the necessity to cultivate a conducive economic environment. Often emerging as a grassroots endeavour, ecotourism relies heavily on the grassroots support of local communities and farmers who provide recreational services. Furthermore, the success of ecotourism is intricately tied to the well-being and financial stability of local residents. As a community-driven sector, ecotourism typically operates independently of financial assistance from international programs and projects.

Contrary to the findings of Kalaitan et al. (2021), it is questionable whether the investment attractiveness of ecotourism in Ukraine will indeed see an increase. The assertion that tax incentives for farmers will adequately bolster rural enterprises appears doubtful, given that small businesses heavily rely on the purchasing capacity of consumers. The author contends that all visitors should be subject to tourist taxes, with the proceeds from environmental taxes either retained by local communities or allocated for the protection of local ecosystems. Our contention is that the proposed fiscal scheme is intricate and lacks a direct impetus for suppliers of rural tourist services. Considering the generally lower economic status of rural residents, we posit that the focus of rural tourism should be on supporting the local population rather than relying solely on tax-related measures.

Borysova et al. (2021) posit that ecotourism inherently embodies resilience during times of crises and facilitates rapid recovery thereafter. As an integral component of a national economy, tourism is subject to various attractors and stakeholders whose survival post crises often takes on a different trajectory. While the objective here is to redirect the internal tourism market, the specific means and rationale for doing so remain unspecified. It is acknowledged that ecotourism operates as an independent and poorly administered business, grappling with numerous risks, fluctuations, and instabilities. Typically, both local authorities and farmers struggle to forecast the number of tourists and anticipate revenues for service providers. Robust models for predicting rural tourist flows are still underdeveloped, as crises, competitive environments, and substitutions for leisure and sporting activities tend to yield multifaceted economic effects. Bondar et al. (2023) assert that ecotourism plays a significant role in mitigating the negative impact
of tourist travel on the environment. However, it is contended that ecotourism alone may not inherently promote environmental sustainability; rather, it necessitates active oversight and regulation by tourism agencies to minimize ecological impact. Implementing additional visa requirements for inbound tourists in Ukraine seems unnecessary, especially considering that ecotourists are typically local residents. Moreover, the standardization and certification of services could potentially stifle ecotourism. While citizen involvement in the daily life of a community is crucial, the primary responsibility for managing the tourism industry lies with authorities rather than local residents.

The focal point of discussion with Seneta and Dubovich (2022) revolves around the establishment of tourism clusters in Ukraine, involving the collaboration of various agencies, suppliers, and local authorities. However, the proposal raises concerns for rural areas, as it may lead to the creation of artificial units. Rural tourism in Ukraine is typically characterized by its chaotic and unstructured nature. Despite this, the primary advantage of rural tourism lies in its significant contribution to social and economic development. It generates additional employment opportunities, creates income for locals, and supports various service providers such as transportation, trade, sports, and entertainment. Enhanced support is imperative for tourism and recreation in mountain regions. The initial rationale stems from the considerable distances between high-altitude villages and urban centers. Remote alpine areas often face challenges in accommodating regular businesses and recreational services due to their isolated nature, even though the unique landscapes of high mountains and secluded hills hold significant appeal for ecotourists and those seeking a slower pace of life. Secondly, mountainous villages typically contend with inadequate infrastructure, outdated utilities, and limited daily services. The third factor is the prevalent issue of low incomes and poverty among the local population. Economic struggles are widespread in major alpine areas across Europe, underscored by the endorsement of various mountain conventions aimed at supporting residents as compelling evidence of the need for assistance.

These factors pose constraints on the advancement of tourism and recreational enterprises in alpine regions, necessitating additional efforts to boost the industry. To achieve this, a flexible development strategy is essential, and the algorithm outlined above can serve as a guide for policy adjustments. Emphasizing recreational activities becomes paramount when an alpine area is surrounded by captivating landscapes and possesses a well-established industry. Recreational entrepreneurs can successfully compete with the agri-industry, provided the natural environment is conducive and economic policies are supportive. Ensuring the sustainability and continuity of facilities such as hotels, spa resorts, camps, and other service providers is crucial. Any gaps or deficiencies in this network can confine areas to being recreational zones for locals only, even if the landscapes are unique and appealing to visitors.

Conclusions

Discussions about the recreation and tourism industry in Ukraine reveal some discrepancy between the available recreational capacities and efficiency of the resources usage. The multilevel algorithm of area classification is the framework to differentiate communities by type of settlements (urban, rural, intermediate or mountainous), proximity to urban centres (urbanized or remote rural areas), recreational resources
capacities (high, medium, or low), and economic impact of the industry (productive, semi-productive, or unproductive). In order to complicate the algorithm, three strategies are proposed for a local recreational policy. They are the recreational focus, the recreational concurrency and recreations for local people. Tourism and recreations in vulnerable areas like alpines are complicated and constrained. The development strategy should be modified and the proposed algorithm can be applied for that purpose. Similarly for recreations in mountain regions, three alternatives are proposed. The first one is the focus on recreations if alpine areas are surrounded by attractive and ecologically functional landscapes and the sustainable tourism infrastructure. The second alternative is the prospective recreation if the industry is capacitive and the environment is friendly. Thirdly, recreations for local people are proposed if there are no solid nets of entities supplying recreational services.

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Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

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Research involving human bodies or organs or tissues (Helsinki Declaration)

The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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To see original copy of these declarations signed by Corresponding/First Author (on behalf of other co-authors too), please download associated zip folder [Declarations] from the published Abstract page accessible through and linked with the DOI: https://doi.org/10.33002/nr2581.6853.070105.
Comparative Assessment of the Mountainous River Basin in Kyrgyz-Kazakh Region of Central Asia with River Basins in Australia, Canada and USA

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Abstract
Central Asia is among the most heavily affected regions worldwide by climate change and water shortages. Impacts include changes in precipitation patterns, more frequent temperature extremes and increased aridity causing a negative impact on agricultural production, food availability, and environmental security. To combat this threat, it is important to enhance information literacy among all water users. This can be done through awareness campaigns, blended learning by providing the proper Technical and Vocational Education and Training (TVET) programs and utilizing all available facilities. This will address relevant issues, such as miscommunication, complexities of transboundary water sharing issues, overexploitation of water resources, and poor flood-drought mitigation techniques. Proper and user-friendly lifelong blended learning for scientific information dissemination focusing water issues can provide stronger support to increase awareness among water users and decision policy makers. Worldwide, especially in North America and Australia, information literacy campaigns have proven successful. This strategy can be replicated in the Mountainous Kyrgyz-Kazakh Chu-Talas transboundary river basin. The issues concerning the Mountainous Kyrgyz-Kazakh Chu-Talas transboundary river basin is elaborated and compared with Australian, Canadian, and US river basin management programs. The foresight analysis is presented, as to what would be a rationale to improve water resources more sustainably in Central Asia. Methodologies, programs, technologies, communities-based river basin committees, snow-water collection with agroforestry, and basin-based water market opportunities were analyzed to assess potential applications in Central Asia region.

Keywords
Sustainability; Central Asia; Foresight; Water resources; River basin
Introduction

Water resources are complicated issues in Central Asia (CA), including the transboundary Kyrgyz-Kazakh Chu-Talas River Basin (CTRB) area. Many problems are related to the outdated water distribution system, poor Technical and Vocational Education and Training (TVET) support, lack of user-friendly database platforms, weak economic incentives for water recycling and flood water storage technologies like Flood-MAR\(^1\) (Managed Aquifer Recharge), and lack of foresight encompassing the proper project preparation activities combining scientific research connected to the business planning.

Water distribution systems in CA lack proper transparency, and water saving incentives, including IT-based water monitoring with climate change and anthropogenic distractions prediction analysis (Mashtayeva et al., 2016; Panichkin et al., 2017). The CTRB, including surface-groundwater resources, are in permanent debates about the water usage in the area (ORDA, 2024; UNECE, 2021). The difficulties in determining the water balance of the basin result from the restricted cross-border collaboration of hydrologists, meteorologists, and hydrogeologists, local people, and farmers (Adenova et al., 2023). The predominance of administrative control in the CTRB, without the local people’s involvement in the decision-making process, creates complexities in the management of water resources. The CTRB water sharing disputes between Kazakhstan and Kyrgyzstan are cooked by the politicians and administrators belonging to these two countries.

The rural people and farmers who live and work in CTRB are not included in decision-making processes, thus preventing them from participating in efficient planning and water usage programs. Due to the lack of proper cooperation, the local people residing CTRB are unable to coordinate the planning and use the resources efficiently integrating proper communications with their neighbors (ORDA, 2024; UNECE, 2021). The proper modeling and calculations of water resources with prediction analysis are missing in context of CTRB. This is a reason why administrators from these two countries give the incorrect calculations about water volume, which farmers may use and, accordingly, they can plan their crop plantations and irrigation activities.

As an example, during the winter season of 2022-2023, the 2023-year prognosis of potential water volume, which farmers might use in the CTRB, was overestimated. Administrators presented optimistic water volume which could become available in 2023 during early springtime. The forecast by the CTRB Hydrometeorological Service reported the water inflow for the growing season (April-September) of 2023 was expected to be in the range of 474–727 million cubic meters, or 115% higher compared to the previous year, i.e. 2022. Considering the forecast, farmers were given optimistic plans for the growing season of 2023, when 222 million cubic meters of water were supposed to flow along the Shu River, and 520 million along the Talas River. On the contrary, due to low night temperatures in spring and early summer, the melting of glaciers was not intense. Therefore, the forecast by CTRB Hydrometeorological Service was not confirmed (Melnik, 2023).

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\(^1\) California’s Flood-MAR Hub. What is Flood-MAR? Available online at: https://floodmar.org/ [accessed 3 December 2023].
The CTRB management is dominated by the administrative system without the local people’s involvement. This management is run mostly relying on the basic supply transactions, when one supplier tries to convince another to achieve something in shortest time as much as possible, without a detailed analysis of the consequences. A proper forecast revealing what may happen in the future, and how these current momentary actions will affect the sustainability of the CTRB environment is missing. In this case study, one side, Kyrgyzstan was found trying to convince the other side, Kazakhstan, about the problems cropping up in context of water volume estimations. On the other hand, the water suppliers from Kazakhstan needed to take water immediately by diminishing the future planned shared amount of water (Airan, 2023; Nurmatov, 2023).

The CTRB residents, farmers and users of water are practically excluded from the decision-making process. How can they use water in their basin or in their region of residence? CTRB’s local residents are excluded from the decision making process in the programs for efficient water use, climate change adaptation, water volume calculations with monitoring in their basins. Residents do not have adequate voice in the program to plan basin-based activities in coordination with other members of the CTRB. Inclusion of people’s voices in decision making is the best strategy to make their shared basin more sustainable. The residents of CTRB lack access to comprehensive lifelong blended learning opportunities, which would include adapting to and mitigating climate change, planning resources in collaboration with family members, and minimizing disruptions for neighboring communities. Additionally, farmers in the CTRB lack adequate information regarding precipitation forecasts, including snow and rain, as well as understanding the water balance and flow within the basin.

**Methodology**

The research methodology is presented below in the graphical flowchart (Figure 1). The water resources planning and management in Kyrgyz-Kazakh Region is compared with the Australian, Canadian and US river basins. This study employed a comparative-descriptive methodology that delves into the intricacies of basin-based water resource system planning and management across global regions, including Australia, Canada, the USA, and the river basins of Kyrgyzstan and Kazakhstan. Subscribing the scholarly insights of Bathelt and Li (2020), the analysis adhered to a dual principle: comparing entities that share commonalities, and focusing on the salient attributes of each entity. By scrutinizing the existing literature, this study aimed to gauge the efficacy of basin management strategies and the economic viability of harnessing natural water resources within these basins. Deriving insights from literature review and collaborative brainstorming sessions within research group², the study identified strategic tools (see Figure 1) suitable for adaptation to the unique context of the Kyrgyz-Kazakh basins.

² The research group has included the diverse cross-disciplinary researchers and local people, farmers from the transboundary area of Kyrgyzstan and Kazakhstan. During the yearly forum of Kazakhstan and Kyrgyzstan scientists, the authors brainstormed about the cooperation and exchange of experience between the scientific communities of both the countries. The forum was dedicated to promoting the development of science, technology and education in the region, and for active discussion on current scientific issues and initiatives. Ministry of Science and Higher Education of the Republic of Kazakhstan, Ministry of Education and Science of the Kyrgyz Republic, National Academy of Sciences of the Republic of Kazakhstan under the President of the Republic of Kazakhstan, and National Academy of Science of Kyrgyz Republic have supported events of the forum.
To enhance the planning and management of water resources within the Kyrgyz-Kazakh basins, several key areas for improvement were delineated. These included bolstering emergency event modeling (capabilities and predictive tools), utilizing resources such as FEMA’s HAZUS. Additionally, enhancing flood water management through tailored programs like Flood-MAR (Managed Aquifer Recharge), fostering transparency in agricultural management via the integration of unified GIS databases with tools like Soil Water Assessment Tools (SWAT) modeling, and optimizing snow-water collection methods through innovative agroforestry approaches.

Moreover, the study advocates for the implementation of basin-based water market programs to incentivize economic efficiency in water resource management. These methodologies and strategies will be expounded upon in subsequent sections, offering a comprehensive framework for advancing basin-based water resource planning and management practices.

Research questions Included:
1) How to improve the current situation in CTRB?
2) How can the CTRB residents and farmers be involved more in joint activities to make their life more sustainable?
3) How to incorporate experience of other countries, including the Canada-US river basins (RRBC, 2023) and Australia? Will they be reasonable to study for a comparative analysis?

Research Area

Kyrgyz-Kazakh Chu-Talas River Basin (CTRB)

The CTRB is one of the CA regional catchments that are shared by Kyrgyzstan upstream and Kazakhstan downstream (Figure 2). CTRB is formed by the basins of the rivers, Chu (Shu) and Talas. Both the rivers source the water from the mountains of Central Tien Shan in Kyrgyzstan at elevations exceeding 4,000 m above sea level (asl) and extend into lower altitudes to the steppes and deserts of Kazakhstan with elevations of about 400 m asl where hills terminate to a topographic depression forming shallow lakes (Figure 2).

The Chu basin receives more precipitation (up to 1,000 mm/year in the high mountains of Tien-Shan) than the Talas River (about 500 mm/year). Talas basin has higher population density (11%) and proportion (5.3%) of arable land (Yapiyev et al., 2017, 2018, 2019, 2020). The Kyrgyz capital, Bishkek, having a population of just over 1 million, is in Chu River upstream area on its tributary, the Ala-Archa (GEF, 2019). Water consumption is dominated by irrigation accounting for over 90% of the basin water usage in the Kyrgyzstan zone of the CTRB (GEF, 2019).

The Canada-US River Basin Commission

The Red River, marking the boundary between North Dakota and Minnesota in the US, flows northward into Manitoba before reaching Lake Winnipeg in Canada. Running through the fertile Red River Valley, this 885 km (550 miles) long river frequently floods during the spring thaw, posing a threat to cities like Winnipeg of Manitoba in Canada;
Fargo, North Dakota; and Moorhead, Minnesota in the US. The Red River basin supports various important fish species such as channel catfish, walleye, and bigmouth buffalo. The Red River traverses the level terrain once occupied by the expansive glacial Lake Agassiz, which originated at the conclusion of the Wisconsin glaciation period from the melted ice of the Laurentide Ice Sheet. The gradual melting of this continental glacier gave rise to the formation of the lake. Across millennia, sedimentation occurred, depositing layers of soil at the lakebed. These lacustrine soils serve as the foundational soils of the present-day Red River Valley (RRBC, 2023). The Canada-US Red River Basin Committee (RRBC, 2023) coordinates water project programs (Figure 3), basin activities affecting cross-border river flows, water quality, and ecosystem well-being.

Figure 1: Block diagram of research methods: Kyrgyz-Kazakh basin-based water resources system planning and management comparison with Australia, Canada and USA

What strategy tools could be used, adapted for Kyrgyz-Kazakh basins?

- Emergency events modeling, prediction tools, as HAZUS
- Flood water accumulation programs, FLOOD-MAR
- Unified Agricultural GIS database with SWAT modeling
- Snow-water collection with agroforestry
- Basin based water market

Basin-based water resources system planning and management
The area of the Murray-Darling basin covers 1,062 thousand km$^2$, which is 14% of mainland Australia (Murray-Darling Basin Authority, 2001), in which about 60 thousand km$^2$ is the floodplain area, or circa 6% of the Murray–Darling River basin area. The Murray-Darling Basin has a diverse landscape, ranging from semi-arid ephemeral river systems in the north to highly regulated river systems in the south, fed by the runoff from Australian Alps. Most of the Murray–Darling River basin consists of extensive plains and low undulating areas, most of them are located at less than 200 m above sea level. A significant part of the catchment area is situated on peaks with the altitude ranging
200-1,000 m. In the easternmost and south-eastern territories, there are hills with a height of more than 1,000 m (Figure 4) (David, 2001).

Figure 3: The Canada-US Red River Basin, marking the boundary between North Dakota and Minnesota in the US, flows northward into Manitoba before reaching Lake Winnipeg in Canada: the fertile Red River Valley, this 885 km (550 mile) long river frequently floods during the spring.
The climate of the Murray-Darling Basin is subtropical in the north, semi-arid in the west, and moderate temperate in the south. The average annual temperature varies between +4 and +11°C. The average temperature in the cold period ranges from -5°C to -10°C, and in the warm period from +16°C to +20°C. Precipitation decreases from high rainfall in the summer period to lesser in winter period, and spatially from the north to the south. On the eastern side of the basin, the average annual precipitation reaches 1,500 mm. On the other hand, in the south, several months observe a fall season every winter on the peaks of the Great Dividing Range. The basin's western side is usually hot and dry, and the average annual precipitation is generally less than 300 mm (Australian Government Department of the Environment, 2016). The evaporation rate in the basin is high, with 94% of the precipitation falling in the basin being used by plants (transpired) or evaporated from land and surface waters (Vagapov, 2003; Vasilenko, 2012).

Climate change studies predict that the basin's climate is likely to become drier and more volatile in the future due to increasing concentrations of greenhouse gases in the atmosphere. Thus, in addition to more extreme droughts, there may be more extreme floods.
What Strategy Tools Can be Used for CTRB?

The challenges related to water resource in Central Asia (CA) present complex issues that necessitate careful diagnosis and strategic solutions. Like treating medical ailments, addressing these challenges effectively hinges upon accurate diagnosis, comprehensive monitoring of past trends, precise forecasting, and rigorous analysis of future scenarios. Success in any endeavor, be it a project or managing water resources, relies on a thorough understanding of the current situation, prudent resource assessment, and adept adaptation of technology to existing conditions. In the realm of Central Asia's water resource management, numerous obstacles stem from various factors. These include the lack of robust scientific support for professional project management, inadequate financial forecasting based on scientific principles, and a dearth of effective collaboration among relevant stakeholders. Furthermore, the absence of unified databases across key ministries in Kyrgyzstan and Kazakhstan exacerbates the issue. These ministries encompass areas such as emergency response, water management, agriculture, internal affairs, and industry. Addressing these challenges calls for a holistic approach akin to viewing the water resource system as an interconnected organism.

Central to this strategy is the establishment of a unified database platform integrating vital information on hydrometeorology, precipitation patterns, surface and groundwater dynamics, pollution sources, disease outbreaks, and water quality assessments. Such a platform would enable scientifically-informed financial assessments tailored to specific problem areas, mirroring successful practices observed in countries like Australia, Canada, and the USA. Many nations are increasingly adopting collaborative frameworks that unite researchers and integrate applied scientific programs in agriculture with disaster mitigation efforts. This convergence involves leveraging the expertise of insurance companies to address potential emergencies such as floods, droughts, fires, and earthquakes. By fostering interdisciplinary cooperation and embracing innovative approaches, Central Asian countries can navigate their water resource challenges more effectively, ensuring sustainable management practices for the future.

Emergency Events Modeling by Prediction Tools

The Canada-US unified Geographic Information Database of Emergency Modeling (FEMA’s HAZUS) provides standardized tools and data for assessing the risk of earthquakes, floods, hurricanes, droughts and fires with economic analysis and scenarios for planning financial expenses in cooperation with insurance companies. The Ministries of Agriculture, Emergency Situations, Water Resources, and Irrigation (WRI) of Kazakhstan and Kyrgyzstan will be reasonable to adapt the HAZUS.

The economic benefit from the effectiveness of proactive actions is calculated by these basic principles, recommended by the main organization, including the UN and the US Federal Agency for Emergency Situations (FEMA). For every dollar invested in advance before an emergency, up to 10 dollars are saved by mitigation consequences of an emergency (NIBS 2023). As the expenses of climate change and anthropogenic disasters increase, the US FEMA is increasingly investing in proactive preparedness to respond effectively. Every

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1 FEMA’s HAZUS Program provides standardized tools and data for estimating risk from earthquakes, floods, tsunamis, and hurricanes. Available online at: https://www.fema.gov/flood-maps/products-tools/hazus [accessed 1 December 2023].
year for the past five years, more than 20 disasters have occurred in the United States, costing more than $20 billion (NIBS, 2020). FEMA's strategy is to become more forward-thinking rather than reactive. Climate change requires planning over decades in advance, but this was not FEMA's responsibility in the past. Now, US FEMA is intensively developing research work on modeling emergency scenarios for decades to come.

On the contrary, the Ministries of Emergency Situations of Kazakhstan and Kyrgyzstan do not have programs like the United States and Canada have, e.g., FEMA's HAZUS. With an investment of several million dollars in similar FEMA’s HAZUS programs, the system can save tens of millions of dollars by mitigating the consequences of an emergency either in Kazakhstan, or in Kyrgyzstan.

**Flood Water Accumulation Programs**

In the programs accumulating drainage flood water using artificial groundwater recharge, application of MAR (Managed Aquifer Recharge) technologies are gaining popularity in many countries, including EU countries Canada and USA (TERESA, 2023). Dependence on surface water and the construction of reservoirs create environmental problems through evaporation, which leads to water loss. The USA and Canada, realizing their mistakes, reduced the amount of surface reservoirs and developed more Flood-MAR technologies for the use and replenishment of groundwater resources, with subsequent use of groundwater during droughts (Figure 4). In the American State of California, due to the intensifying water crisis, the government is encouraging the population and farmers to use more Flood-MAR technology with funding from grants and soft loans, ceasing support for the construction of dam reservoirs. The benefits and effectiveness of the implementation of Flood-MAR programs in increasing flexibility in water resource management and drought resistance, with regional self-sufficiency in increasing water supply and flood protection. Investments in Flood-MAR have high returns.

MAR provides valuable social benefits and promotes the conservation of groundwater resources (TERESA, 2023). There is no consensus on the appropriate method to estimate the social discount rate (SDR) for social infrastructure projects. The two most used alternatives are the social rate of time preference (SRTP) and the social opportunity cost of capital (SOC). SRTP is the rate at which a society is willing to save a unit of current consumption in exchange for more consumption in the future. Using this approach, recent UK SDR estimates have been in the range of 3.5–3.75%. (Freeman et al., 2020). The US Council of Economic Advisers suggests testing the sensitivity of social infrastructure proposals using alternative discount rates, suggesting rates of 3% and 7% (White House, 2024). By using these social important investment approaches in the MAR technologies based on the credit rate of 3%, the MAR will fully pay back approximately in 30 years (Zheng et al., 2021).

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5 https://www.mercatus.org/research/policy-briefs/social-discount-rate-primer-policymakers


At the same time, while analyzing the economic effect of Flood-MAR in terms of the rational use of budgetary funds for flood emergencies, according to the US Federal Emergency Management Agency (FEMA), for every dollar invested in advance before an emergency, up to $10 is saved on consequences of emergency situations (NIBS, 2020). At $10 million in flood costs, implementing Flood-MAR technologies could save $9 million with an initial upfront investment of $1 million in Flood-MAR. Moreover, the agricultural efficiency of Ag-MAR demonstrates that there is potential to increase regional recharge by 7–13%, to increase crop consumption by 9–12%, and to increase natural vegetation consumption by 20–30% (Levintal et al., 2023). Ag-MAR has great potential to improve the long-term sustainability of water resources in agricultural regions (Levintal et al., 2023). In Kazakhstan, the Ministries of Emergency Situations, Water Resources and Agriculture are disintegrated; each is a Ministry in itself. No cooperation programs like Flood-MAR do exist in Kazakhstan and Kyrgyzstan.

**Unified Agricultural GIS Database with SWAT Modeling**

The Canada-USA Department of Agriculture’s SWAT Unified Geoinformation Database⁸ (USDA, 2023) is utilized for soil and water resource monitoring with modeling of the quality and quantity of surface and groundwater and predicting the environmental impacts of land use, land management and climate change. SWAT (Figure 5) is widely used to assess and plan the soil erosion prevention and control, nonpoint source pollution control, and regional watershed management (Sagin et al., 2016, 2017; Sagintayev et al., 2011, 2015).

Modeling tools simulate the functioning of ecosystems and their interactions with human activities to help make decisions and evaluate management strategies. This leads to informed decisions that balance human development and environmental protection. Among these models, the Soil and Water Assessment Tool (SWAT) stands out for its ability to model a variety of biophysical processes that may be associated with the provision of ecosystem services (ES). SWAT has been successfully used to assess ecosystem services, further helping to translate SWAT results into monetary terms, as the FEMA’s HAZUS does in disaster response cases. Both the modeling programs are available as a geoinformation platform having GIS data processing system and uniform GIS standards. In addition to the fact that SWAT can be used in tandem with US FEMA’s HAZUS disaster management, SWAT promotes more efficient planning and use of water resources with analysis of soil receiving fertilizer inputs at a particular water quality. SWAT allows farms to optimize costs by up to 70% through preparing models for optimal land use conversion for all crops and rangelands. It can be used by analyzing the net present value of 10-year farm profits and load reduction, coupled with the cost-effectiveness ratios (Liu et al., 2019). If, for example, farmers’ expenses are about $10,000, then with the effective use of SWAT modeling technologies, expenses can be optimized up to 70%, or $7,000, and the farmer will need to spend a smaller amount of about $3,000.

In Kazakhstan, there are no agricultural modeling programs like the modeling programs of the US Department of Agriculture SWAT.

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⁸ WEG Model Development, *Canadian Version of Soil and Water Assessment Tool (CanSWAT)*. Available online at: https://geog.uoguelph.ca/weg-model-development [accessed 28 September 2023].
Community Based River Basin Committees

The Canada-US programs for scientific collaborative management of transboundary river basins, e.g. Saskatchewan River Basin, Global Institute for Water Security, Canada-US Red River Basin Commission (RRBC, 2023), are good candidates to investigate for potential adaptation in Kyrgyz-Kazakh CTRB. Community based committees should be created in river basin areas, together with neighboring countries. Possible applications include ownership of water resources and reservoirs, mutual responsibility for maintenance, financing and security, and maintaining a unified geoinformation database for modeling emergency situations. Platforms such as FEMA’s HAZUS can be used for assessing the risk of earthquakes, floods, droughts, and water accumulation (Flood-MAR). The Kazakh Academy of Science, together with the Ministries of Agriculture and Emergency Situations, can strengthen the work of basin committees (Figure 1, 2) with the involvement of scientists. A pilot program of research for the CTRB, consisting of two regions of Kyrgyzstan (Chu and Talas) as well as Zhambyl region of Kazakhstan, in cooperation with basin committees and Water Security Institutes of Canada-USA, can be developed (Water for Food, 2023).

National Academy of Kazakhstan/Kyrgyzstan scientists could establish programs of research, training, and participation in conferences jointly with Canada-USA. Basin management through basin committees makes it possible to manage the water resources of river basins more effectively by residents, farmers, and local organizations in the river basin. As a result, emergency risks are reduced, and water consumption per unit of grown product becomes more predictable. The expensive bureaucratic system of administrative (ministerial) management is eliminated, and water resources are managed by basin’s water users. Efficient use of water resources allows farmers in the basin to plan better. Incomes have increased several times with the same volume of water used per unit of grown product through the coordinated use of forecast programs, such as FEMA’s HAZUS, Flood-MAR, and SWAT. The path to sustainable development hinges on minimizing the expenses associated with cumbersome bureaucratic administrations and adopting contemporary technologies. This transition involves granting ownership of resources to local residents and users of water within the basin. Additionally, it entails overhauling water rights through market-oriented environmental programs, thereby fostering opportunities for natural restoration of water resources.

Snow-Water Collection with Agroforestry

The Canada-USA Ministries of Agriculture have spearheaded scientific initiatives aimed at augmenting forest cover. One key aspect involves compelling land users to undertake the planting and maintenance of forests along reservoirs, extending to the width of these reservoirs. This strategic approach also encompasses areas crucial for snow-water retention. Investigating the potential adaptation of such programs for the Kyrgyz-Kazakh Central Transboundary River Basins (CTRB) holds promise for bolstering regional resilience. Furthermore, the promotion of programs integrating forest plantations for snow-water retention with Flood-MAR (Managed Aquifer Recharge) technologies in the USA and Canada is gaining momentum. These initiatives come with comprehensive guidance, advanced training programs in colleges, and grant systems designed to incentivize the farmers. Studies suggest that the combined utilization of forest
plantations in agricultural landscapes can elevate overall productivity by up to 30% compared to conventional crop cultivation methods (Wilson and Lovell, 2016).

The financial benefits of agroforestry practices manifest in various forms. Firstly, there are direct outputs derived from the tree and shrub components. Secondly, there is indirect productivity enhancement attributable to these components. Thirdly, there is a reduction in external factors, facilitated by the support of trees and shrubs (Agriculture and Agri-Food Canada, 2010). Moreover, agroforestry systems yield enhanced ecosystem services, including heightened resilience, increased biodiversity, carbon sequestration, and improved water quality. Notably, the integration of snow-water retention techniques with Flood-MAR technologies ensures a more stable and predictable water supply, further amplifying the ecological and economic benefits of agroforestry practices in the region.

**Groundwater Resources – Geological Hydrogen**

Numerous countries are currently engaged in "white" hydrogen exploration, akin to a modern-day gold rush. This fervor extends to regions like the German-French border, which boasts the world's largest underground reserves of "white" hydrogen. On the territory of the transboundary Moselle-Saar River basin, where coal mines abandoned more than 20 years ago, are located large volumes of natural geological “white” hydrogen, discovered with an estimated volume of up to 250 million tons (Bettayeb, 2023). It is important for underground hydrogen “factories” to replenish water for the physico-chemical oxidative processes of serpentinization, the process for hydrogen production underground (Ellis, 2023; Hand, 2024). Kazakhstan, or Central Asia as a whole, does not have “white” hydrogen exploration activities and does not have the “gold rush” programs dedicated to underground geological “factories” identifications. Central Asian countries may expand cooperation in efficient use of groundwater resources together with keeping sustainability of natural geological “white” hydrogen production (Figure 5). Such programs can improve regional cooperation. This program can be connected with the NEXUS-water, food, energy activities.

![Figure 5: The diagram exhibits a potential of Central Asian countries for cooperation in groundwater resource use to prospect natural geological “white” hydrogen production (adapted from Ellis, 2023; and Hand, 2024)](image-url)
Basin Based Water Market

Like many countries, including Central Asia, Australia is prone to floods and droughts. The recurring cycle of floods and droughts in the Murray-Darling River basin with the necessity to improve resource management and to mitigate environmental degradation has led Australia to urgent reforms in their water management system. The adopted Australian reforms are considered a global breakthrough in the field of environmental management. The reforms were promoted in 4 key areas:

1) Transformation of the water distribution inside the basin. Australia has moved from the old method of allocating water resources with limited environmental restrictions to a new flexible market-based system. Australia has established limits on the total water use in catchment basins and provided economic value for individual right holders of water resources within the basin.

2) Improving environmental management. Australia has legally fixed the limits of water volume taken from the basin, thus guaranteeing stable water use in the future.

3) Reforming the pricing of water supply services. Australia has introduced a pricing regime based on the volume of water consumption and reimbursement for efficient water use.

4) Modernization of the mechanism of providing services for water users. Australia has divided water resources management functions establishing service standards, and implementing measures to comply with regulatory requirements. Australia optimized water resource administrative organizations with service provision and financial efficiency improvement. All data related to surface-groundwater use and movement is made transparent and available at any time to all people. In irrigation areas, the management of the basin’s water resources has been transferred to local authorities under personal responsibility so that everyone can contribute to decision-making ensuring a balance between water prices and the level of service (Jane, 2016). Governmental administrative and ministerial management are significantly reduced in Australia.

Australian basin-based water market system will be reasonable for the Central Asian region to investigate, to study. How potentially this approach may improve the current water crisis issues in Central Asia? Of course, it will be complicated to implement a same approach for the whole Central Asia region, for all five Central Asian (Kyrgyzstan, Kazakhstan, Uzbekistan, Tajikistan, and Turkmenistan) countries. These countries already spend dozens of years trying to improve situation with the Aral Lake basin to shrink disasters without success. Afghanistan now is building a huge canal to take water from the Amu Darya River, which is a sub-basin of the Aral Lake basin. So, the Central Asia region is moving to the many water disasters. The more efficient sustainable approaches should be implemented to improve the current water status. Kyrgyzstan and Kazakhstan are similar in their administrative systems, and their local people are well connected. Economically, these two countries are also well connected. Hence, proposing the same water market approach CTRB river basin can be manageable. However, proper training and capacity building programs will be necessary to set up, preferably, in cooperation with Australian water experts.
Discussion: Basin-Based Water Resources System

Central Asian countries, including Kyrgyzstan and Kazakhstan, have systemic problems in their water resource management. Central Asian countries miss a well-integrated user-friendly and transparent database platform through which local people can understand water management procedures. The local people within the Central Asian basins are excluded from decision-making activities. Discrepancies in water resource indicators and the lack of objectively reliable information reflecting the surface groundwater resources status create complexities for local people. Central Asia lacks consistent water resources management, and the ministerial administrators' interventions confuse many people. Moreover, proper scientific support is also absent in water resources linking with well-connected TVET programs (Baykhozha, 2023).

The water resource information database with related water management facilities in Kazakhstan is privately owned by "Kazgiprovodkhoz". The state water cadaster certification is not publicly available. Water management facilities lack proper monitoring systems. One water distribution organization, "Kazvodkhoz", is responsible for the two competing tasks: a) the general water facilities constructions, and water monitoring tools installation; b) quality control of construction, and certification programs. While delivering the services, the "Kazvodkhoz" and its branches combine two competing responsibilities as a customer and a contractor (Kharlamov, 2019).

Currently, 60-70% of the water consumed is used for irrigation in Kazakhstan, with a considerable water loss; more than half of the irrigation water is lost due to inefficient irrigation systems (Ilyasov, 2023). Efficient water resource programs reduce the impending environmental problems together with optimizing the existing management methods having an increased economic benefit for the people. Such programs also involve the local people in the decision-making process on the pattern of RRBC (2023) and the Murray-Darling River basin of Australia.

Agriculture in Central Asia, including Kyrgyzstan and Kazakhstan, is also inefficient with considerable water consumption, compared to Australian agriculture. The industry and public utilities of Kazakhstan pollute the environment making the water quality worse. The significant water volume is taken by heavy industry in Kazakhstan. After industrial use, the polluted water is often discharged back into the streams adding further to the environmental toxicity. The interests of large industries are on higher priority in Kazakhstan than the interests of the people in the rural regions (Burlibayev, 2014). Kyrgyzstan and Kazakhstan have similar issues with water resources, flood-drought problems with a necessity to improve the water efficiency, to set up more water sustainability programs.

Experience of the Canada-US Red River Basin Commission

The Canada-US Red River Basin Commission (RRBC) oversees the implementation of flood-and drought related issues, including financial, efficient use of water resources. Local residents, farmers, and First Nations people living in the three US states of Minnesota, North and South Dakota and the Canadian province of Manitoba are actively involved in the implementation of projects for the efficient use of water resources. Civil societies organizations involved in the protection of nature, flora and fauna also actively...
participate in water resource management. Water technicians are affiliated with the projects, and they have strong local capacity of managing their water resources with financial and technical inputs. Permanent lifelong blended training related to water issues are provided to everybody in the Canada-US river basin. The rural regional libraries are used intensively for regular meetings, seminars, and planning activities (RRBC, 2023).

The RRBC maintains all databases, open and accessible to everyone. Information about each project and the group leading the project is available freely on an open access website. For example, in the basin, residents and farmers decided to take LIDAR (Light Detection and Ranging)\(^9\) Remote Sensing with high-resolution images of 50 cm to create topographic maps, digital elevation models, land planning for farmers, modeling floods and droughts. Accordingly, $5 million were spent on this, with a contribution of $3 million from local farmers and $2 million from the provincial administration. As a result, the open access LIDAR data is available for everybody to download. Moreover, training programs on the use of LIDAR is also given to everyone, with modeling programs on climate change forecasting and adaptation. For the effective use of accumulation of drainage and flood waters, the Basin Committee uses intensive modeling and, in consultation with farmers in Canada and the USA, determines the locations where it will be optimal to create small reservoirs for replenishing underground aquifers. Such a modeling is done through the Flood-MAR programs operating in California.

Experience of Australian Basin System

Australia has a well-developed agrarian farming support system with a personalized service system in the remote rural areas, including territories of Indigenous aboriginal people, with regulated attention to the protected wetland system. The current Australian policy was initiated in the 1990s. Since 2000, the water consumption per crop cultivation has decreased rapidly. Over 10 years, the water use indicator has reduced by 2.5 times. At the same time, the agro-production output has not undergone significant changes in Australia. The gross income from the agro-business has continued to grow in Australia. On the other side, Kazakhstan is missing such an efficient water consumption program; the agro production output is directly related to the consumed volume of water. Agriculture is continuously facing resource depletion, swamp formation, and land desertification. The interests of big industries are on the priority in Kazakhstan. Small farms in remote rural regions of Kazakhstan are poorly supported. The facilities giving information about surface and groundwater network are not user friendly and are not accessible to ordinary people in Kazakhstan.

In the Murray-Darling basin of Australia, the yield of products shows small fluctuations due to the presence of a detailed branched web of water supply to every resident, farmer and agricultural producer in rural regions. The system of surface and underground water resource facilities is interconnected, and all the data are transparent and accessible to everybody in Australia. People have more incentives to use water more efficiently. Even in water crisis periods, farmers may purchase water from those who have used water more efficiently, or have recycled the water, in Australia. People have more incentives to collect water during the flood seasons and upon heavy precipitation, and to develop

underground managed aquifer recharge (MAR) to reduce water losses due to evaporation. This strategy allows the mitigation of natural disasters and floods by storing water with low losses, and using water during droughts.

In Kazakhstan, the attitude to ownership rights over energy and water resources are completely different. The owners of energy resources and industry are a small group of people. Water resources are considered less valuable in comparison with energy resources and industry activities. The ownership of water resources is practically absent and poorly regulated in Kazakhstan. On the contrary, water in Australia is an asset and a mean of earning money. In Australia, every citizen has the right to own a certain amount of water resource. The water of the typical basin is the property of every person who lives in its catchment area. Each resident has the right to a certain amount of water. It becomes rational for engineering companies to build water facilities to preserve water resources during floods, to protect water and then to offer the collected water in the market to those regions where there is demand.

**Basin System in Kazakhstan and Central Asia**

In Kyrgyzstan/Kazakhstan, as well as in Central Asia as a whole, there is no concept of ownership of water resources by the ordinary people of a particular basin. In Central Asia, there is no incentives to restore or keep water, resulting into each resident uses as much water as he/she deems appropriate. Water is underestimated as a resource. Ordinary people do not have incentives for saving water out of its efficient usage. Creating conditions for ordinary people to earn money by saving water will catalyze more efficient use of the water resources in Central Asia. Moreover, each country carries significant expenses for governmental administration, including large budgets for the emergency agencies. This whole administrative system exhibits limited productivity. At the same time, the public resources need to be redistributed to spend on the training of technical specialists, hydrologists, and hydrogeologists (Adenova et al., 2023; Baykhozha, 2023).

**Conclusion**

Effective water management systems in Central Asia are vital for sustainable development. This can be achieved by implementing a few successful examples of other countries’ successful strategies. Replicating successful models can improve the complex current situation in the transboundary CTRB area. Due to the overwhelming administrative control in the CTRB, farmers who live and work in rural areas are excluded from decision-making processes, making it next to impossible for them to take part in efficient planning and democratic water usage initiatives. To increase the sustainability of water resources in Central Asia, it is important to strengthen the transparency of the river basins economy. The local people should be involved in solving their problems by providing them with high-quality secondary technical education on the use of common database platforms with user-friendly software, alongside technical and financial education.

It would be advisable to explore adaptive tools and technologies, such as FEMA’s HAZUS, Flood-MAR, and water market approaches, for Central Asian regions. This includes technical and financial assessment and analysis of the risks of earthquakes, floods,
hurricanes, droughts, fires. A user-friendly monitoring system can improve communities’ resilience. Moreover, it is important to involve the local people and farmers in solving their problems concerning the river basin issues, while subscribing the ideas from the example of Australia, Canada, and the USA. Geospatial information technologies, such as Google Earth Engine (GEE), can assist in monitoring land and water resource usage. Integrating these tools with existing financial programs can significantly expand its effectiveness. This technology can enhance economic efficiency through implementing proactive actions, such as preparing for emergencies; these proactive measures have the potential to save 10 dollars for every dollar invested pre-emergency.

Many problems in the projects are associated with the factors of weak scientific support extended to professional project management of water resources, weak scientific forecast of financial expenses, and absence of unified databases. Many departments of the ministries in Central Asia, including those that manage emergency situations, water, agriculture, economy, internal affairs, and industry, are disconnected and compartmentalized. It would be helpful to develop a unified platform for hydrometeorology of precipitation, movement of surface-groundwater, consumer points, scientific assessment of financial costs, and prediction of problems. Interdisciplinary cooperation is required to improve the sustainability in Central Asian region. Water-saving technologies and innovations, as well as a transition to integrated basin-wide management, can mitigate the growing scarcity of water resources in Central Asia.

Central Asian countries are vulnerable to climate change, disruptions in global and regional water cycles, transboundary non-cooperation, and exploitative water-intensive industries. In Kazakhstan, if current policies continue, available water resources may be reduced by 30-50% by 2030, which will entail significant restrictions in food production, apart from drinking water limitations and ecosystem degradation. In these conditions, the transition from conflicting water supply systems to joint basin management is important, in addition to inclusion of innovations and water-saving technologies. A sustainable approach to lifelong blended learning, tailored for ease of use, can effectively disseminate scientific information about water issues. Scaling up such initiatives would greatly enhance awareness among both water users and policy makers.

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Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

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Modelling Habitat Suitability and Distribution of the Endemic Mindanao Horned Frog (*Pelobatrachus stejnegeri*) and its Response to Changing Climate

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**Abstract**
Climate change is already affecting biodiversity, with special concern to endemics whose range is restricted and limited. This study focuses on the Mindanao horned frog (*Pelobatrachus stejnegeri*), an endemic species to the Philippines, susceptible to climate-induced habitat changes. Using MaxEnt species distribution model (SDM), the current and future (year 2050 projections) habitat suitability and distribution of *P. stejnegeri* were modelled. Results showed that annual mean temperature, elevation, and annual precipitation were the environmental variables having the highest influence on *P. stejnegeri*’s distribution. The model predicts a significant range contraction under representative concentration pathways (RCP) future scenarios (RCP 2.6 and RCP 8.5), with a more pronounced decrease in distribution (31.72%) under the high emission scenario (RCP 8.5). These findings emphasize the vulnerability of *P. stejnegeri* to climate change and highlight the importance of integrating SDM into conservation and management strategies to protect endemic species under changing climatic conditions.

**Keywords**
Mindanao horned frog; Species distribution model; Climate change; Species distribution

**Introduction**
Climate change presents a substantial threat to biodiversity by causing unprecedented changes in ecosystems (IPBES, 2019; Román-Palacios and Wiens, 2020). The effects of climate change on biodiversity are substantial and intricate, encompassing changes in habitat distribution, alterations in species interactions, and a greater probability of extinction (Bellard et al., 2012; Pecl et al., 2017). Moreover, changes in climate can lead to a shift in species' habitats.
and distribution (Pecl et al., 2017), which endangers the existence of multiple organisms (Chen et al., 2011; Trew and Maclean, 2021).

Climate-driven changes in species’ potential distribution can be assessed using species distribution model (SDM) (Zurell et al., 2023). SDM can be used to predict suitability of habitats for different species under different environmental conditions making it an extremely significant tool for conservation planning and decision-making (Rahman et al., 2019). This modeling approach is especially beneficial for species that are vulnerable to climate change, such as the Mindanao horned frog. The predictive capability of SDM enables the targeted allocation of conservation areas, highlighting the significance of focusing conservation efforts in areas of high conservation value, especially for endemic species with restricted ranges (Guisan et al., 2013).

Amphibians, due to their distinct physiological requirements and life cycles, are exceptionally susceptible to the consequences of climate change, making them one of the most endangered animal groups (Hof et al., 2011; Li, Cohen and Rohr, 2013; Luedtke et al., 2023). Fluctuations in temperature, changes in rainfall patterns, and an increased occurrence of severe weather events greatly affect the ability of amphibians to survive, reproduce, and spread (Li, Cohen and Rohr, 2013; Campbell, Miller and Muths, 2020; Rollins-Smith and Le Sage, 2023). These impacts are intensified for endemic species whose distribution is restricted and limited (Manes et al., 2021) urging the call for additional studies for this vulnerable group (Luedtke et al., 2023).

The Mindanao horned frog (*Pelobatrachus stejnegeri*) is an endemic amphibian species found exclusively on the island of Mindanao in the Philippines. It is known for its unique ecological role and its importance as a bio-indicator (IUCN SSC Amphibian Specialist Group, 2020). This terrestrial frog is commonly found in both main and secondary montane and lowland rainforests having mountain streams as the primary breeding grounds. Being endemic, these species are extremely susceptible to habitat alterations resulting from climate change, mostly due to their specific biological requirements and restricted geographic range (Bickford et al., 2010; Manes et al., 2021). However, no studies have been conducted yet, exploring the habitat suitability and distribution of the Mindanao horn frog and assessing its response under changing climates.

This study aims to model the distribution of the endemic Mindanao horned frog (*P. stejnegeri*) under current and future climatic conditions. Additionally, it aims to measure the impact of climate change on this species’ geographic distribution through determination of regions where the habitat may become more or less suitable based on future climate scenarios.

**Methodology**

**Study Area and Occurrence Records**

The study was carried out in the island of Mindanao in the Philippines, where *P. stejnegeri* is endemic (Figure 1). Mindanao is located in the southern part of the Philippines and is one of the three island groups of the country, covering an approximate land area of 95,468.17 square kilometers (PhilAtlas, 2022). The occurrence points of *P. stejnegeri* were collected from the Global Biodiversity Information Facility.
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Duplicate geographic coordinates and coordinates falling outside the study area boundary were removed from the data points to clean them up. Using SDMtoolbox (Brown, Bennett and French, 2017), the distribution data were subjected to spatial rarefaction at a 5 km distance in order to eliminate sampling bias and spatial autocorrelation.

Environmental Variables

This study utilized 21 environmental layers with a spatial resolution of 30 seconds to create a distribution model of *P. stejnegeri*. These include topographical factor (elevation), vegetation factor (enhanced vegetation index), and bioclimatic factors (bio 1–19). The bioclimatic factors were the following: Bio1: Annual Mean Temperature; Bio2: Mean Diurnal Range; Bio3: Isothermality; Bio4: Temperature Seasonality; Bio5: Max Temperature of Warmest Month; Bio6: Minimum Temperature of Coldest Month; Bio7: Temperature Annual Range; Bio8: Mean Temperature of Wettest Quarter; Bio9: Mean Temperature of Driest Quarter; Bio10: Mean Temperature of Warmest Quarter; Bio11: Mean Temperature of Coldest Quarter; Bio12: Annual Precipitation; Bio13: Precipitation of the Wettest Month; Bio14: Precipitation of the Driest Month; Bio15: Precipitation Seasonality; Bio16: Precipitation of the Wettest Quarter; Bio17: Precipitation of the Driest Quarter; Bio18: Precipitation of the Warmest Quarter; and Bio19: Precipitation of the Coldest Quarter. Elevation data were obtained using the digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM), which has a 90 m spatial resolution. The Enhanced Vegetation Index (EVI) map was obtained from Moderate-Resolution Imaging Spectroradiometer (MODIS) data.
Bioclimatic factors were obtained from the WorldClim database (Fick and Hijmans, 2017; http://www.worldclim.org). All layers were resampled based on a bilinear interpolation in order to match the resolution.

In order to prevent overfitting and identify the most appropriate variables, a correlation analysis was performed using Pearson's correlation coefficient ($r$) to examine the relationship between the 21 environmental variables. A Pearson's correlation value greater than 0.7 signifies a strong correlation between the two variables. All but one of any given environmental layers with a high correlation with other layers were removed.

For future climate, bioclimatic variables using the MIROC-ESM climate model for the period 2041–2060 were downloaded from the WorldClim database (http://www.worldclim.org). Two representative concentration pathways (RCP), namely RCP 2.6 and RCP 8.5, were used as scenarios to predict future climate change. The RCP2.6 and RCP8.5 scenarios reflect low and high greenhouse gas emissions in the future, respectively.

Species Distribution Modelling

The species distribution models were created using MaxEnt v. 3.4.4 (Phillips, Anderson and Schapire, 2006). MaxEnt modeling was conducted by allocating 25% of the occurrence data for testing purposes and 75% of the occurrence data for training purposes. In order to identify the primary environmental factors that influence the distribution of *P. stejnegeri* habitat, a jackknife permutation analysis was performed to rank the environmental factors based on their percentage contribution. In order to assess the effectiveness of the MaxEnt model, the area under the receiver's operating curve (AUC) was employed as a measure of the model's predictive accuracy. A model's prediction accuracy increases as the Area Under the Curve (AUC) value increases. Evaluation of model performance were based on three specific criteria: poor, defined as an AUC value below 0.8; good, defined as an AUC value between 0.90 and 0.95; and excellent, defined as an AUC value above 0.95. Once the model computations were finished, the habitat distribution of *P. stejnegeri* was displayed on ArcMap.

The continuous habitat suitability maps of *P. stejnegeri* for both current and future climate conditions (RCP 2.6 and RCP 8.5) were transformed into presence/absence binary maps using a 10 percentile training presence clog threshold. In order to evaluate the changes in the distribution of *P. stejnegeri* due to changing climate, binary maps representing the current climate conditions were overlaid onto the projected habitats and compared using the SDMtoolbox in ArcMap. Afterwards, the results were categorized into three distinct groups: (1) range expansion, (2) no occupancy (absent in both), (3) no change (present in both), and (4) range contraction.

Results

Variables Correlation and Selection

The correlation analysis of all 21 predictor variables showed a high correlation for some variables, as shown in figure 2. The variables with the highest correlation are Bio6, Bio9, Bio10, and Bio11 in relation to Bio1, which has a correlation coefficient above 90%
positive correlation. Nine variables were selected out of 21 variables after the variable selection process, namely Bio1 (Annual Mean Temperature), Bio2 (Mean Diurnal Range), Bio3 (Isothermality), Bio4 (Temperature Seasonality), Bio12 (Annual Precipitation), Bio15 (Precipitation Seasonality), Bio18 (Precipitation of Warmest Quarter), Bio19 (Precipitation of Coldest Quarter), and elevation.

![Figure 2](image.png)

Figure 2. Correlation analysis of 21 predictor variables. a.) Heat map showing the correlation between variables, b.) Dendrogram showing the grouping of highly correlated variables with correlation coefficient threshold of 0.7.

**Key Environmental Factors Influencing the Habitat Distribution**

The importance and contribution of each environmental variable to the prediction model were analyzed by the jackknife method. The results showed that the contributions of Bio1 (Annual Mean Temperature), Elevation, and Bio12 (Annual Precipitation) were 24.39%, 18.65%, and 17.21%, respectively (Table 1). The environmental variable with the highest gain when used in isolation is Bio1 (Figure 3), which, therefore, appears to have the most useful information on the distribution of *P. stejnegeri*. The environmental variable that decreases the gain the most when it is omitted is Bio4, which appears to have the most information that is not present in the other variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent contribution</th>
<th>Permutation importance</th>
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</thead>
<tbody>
<tr>
<td>Bio1</td>
<td>24.39</td>
<td>28.31</td>
</tr>
<tr>
<td>Elevation</td>
<td>18.65</td>
<td>2.026</td>
</tr>
<tr>
<td>Bio12</td>
<td>17.21</td>
<td>11.42</td>
</tr>
<tr>
<td>Bio4</td>
<td>14.17</td>
<td>18.61</td>
</tr>
<tr>
<td>Bio2</td>
<td>9.47</td>
<td>18.19</td>
</tr>
<tr>
<td>Bio18</td>
<td>8.2286</td>
<td>19.5545</td>
</tr>
<tr>
<td>Bio19</td>
<td>7.0256</td>
<td>0.1321</td>
</tr>
<tr>
<td>Bio3</td>
<td>0.4861</td>
<td>0.1612</td>
</tr>
<tr>
<td>Bio15</td>
<td>0.3655</td>
<td>1.5926</td>
</tr>
</tbody>
</table>
Figure 3: Jackknife test of variable importance on *P. stejnegeri* distribution

**Modelled Distribution of *P. stejnegeri* under Current Conditions**

The Maxent model predicts the distribution of *P. stejnegeri* across the entire island, as shown in figure 4. The species’ current modeled distribution closely matches the region's published distribution data, including the range map produced by the IUCN (International Union for Conservation of Nature, 2024). The presence/absence binary map showed that the entire area where *P. stejnegeri* is predicted to be present is 38,550.18 km². The model AUC value of 0.917 indicates that the model's performance is superior to random prediction, hence confirming its validity.

Figure 4: Species distribution model of *P. stejnegeri* under current conditions.

a.) MaxEnt model of *P. stejnegeri* showing probability of occurrence; 
b.) Presence/absence map of *P. stejnegeri*; c.) Receiver operating characteristic (ROC) curve for evaluating the model performance of MaxEnt model.
Modelled Distribution of *P. stejnegeri* under Future Climate Scenarios

Using the MIROC-ES model, the distribution of *P. stejnegeri* is projected under future climatic scenarios. Both models under RCP 2.6 and RCP 8.5 indicated a decrease in the species' range, as shown in figure 5, using the 10th percentile threshold cutoff. The predicted extent of *P. stejnegeri*’s present under RCP 2.6 is 17,890.26 km², but in RCP 8.5 it is 8,452.72 km². The findings indicated a decrease in the extent of the area occupied under projected future climate conditions.

![Species distribution model of *P. stejnegeri* under future conditions (2050). a.) MaxEnt model showing probability of occurrence under RCP 2.6; b.) MaxEnt model showing probability of occurrence under RCP 8.5; c.) Presence/absence map under RCP 2.6; d.) Presence/absence map under RCP 8.5.](image)

Figure 5: Species distribution model of *P. stejnegeri* under future conditions (2050). a.) MaxEnt model showing probability of occurrence under RCP 2.6; b.) MaxEnt model showing probability of occurrence under RCP 8.5; c.) Presence/absence map under RCP 2.6; d.) Presence/absence map under RCP 8.5.

Figure 6 illustrates the geographical areas where the distribution of *P. stejnegeri* will expand and contract in response to changing climate conditions, as determined by different RCPs. According to the RCP 2.6 climatic scenario for the year 2050, the suitability for *P. stejnegeri* would decrease, resulting in a total range contraction area of 23,164.77 km² (Table 2). The majority of the contractions are located in the northern...
region of Mindanao. On the other hand, under the extreme climate scenario (RCP 8.5), the area of suitable habitat is predicted to be greatly reduced, with a total contraction range of 30,200.16 km², or 31.72% contracted in reference to the current model. The areas where no change occurs, i.e., species that are predicted to be present in both current and future climatic scenarios, are primarily concentrated in the high-elevation parts of Mindanao.

![Figure 6: Distribution changes of P. stejnegeri from the present climate to the future year (2050) under climate scenarios: (a) RCP 2.6; (b) RCP 8.5.](image)

<table>
<thead>
<tr>
<th>Distribution Change</th>
<th>Total area of change (km²)</th>
<th>Percentage of change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCP 2.6</td>
<td>RCP 8.5</td>
</tr>
<tr>
<td>Range expansion</td>
<td>2,519.68</td>
<td>101.99</td>
</tr>
<tr>
<td>No occupancy</td>
<td>54,116.55</td>
<td>56,534.24</td>
</tr>
<tr>
<td>No change</td>
<td>15,400.04</td>
<td>83,64.65</td>
</tr>
<tr>
<td>Range contraction</td>
<td>23,164.77</td>
<td>30,200.16</td>
</tr>
</tbody>
</table>

**Table 2: Relative changes in P. stejnegeri distribution area under climate scenarios RCP 2.6 and RCP 8.5 for the year 2050.**

**Discussion**

The present distribution modeling of *P. stejnegeri* is crucial for understanding the environmental factors that influence its distribution. The MaxEnt model precisely delineates the habitat range of *P. stejnegeri*, exhibiting a close correspondence with established distributions and conservation evaluations, such as those undertaken by the IUCN. The high AUC score validates the model's accuracy in identifying the significant environmental factors that influence the distribution of *P. stejnegeri*. The importance of the average annual temperature, altitude, and annual rainfall in the model emphasizes the species' reliance on these biological parameters. This is consistent with overarching ecological theories that credit temperature and precipitation as the primary factors that
influence patterns of species distribution (Bickford et al., 2010; Guisan and Thuiller, 2005; Mi et al., 2022). The mean annual temperature significantly influences the distribution of amphibians, as these organisms, being ectothermic, depend on external heat sources to regulate their body temperature. The metabolic rates, reproductive cycles, and survival of frogs are intricately linked to the prevailing ambient temperature conditions (Rollins-Smith and Le Sage, 2023). Wake and Vredenburg (2008) have provided evidence of the significant impact that changes in temperature patterns can have on amphibian populations. The vulnerability of *P. stejnegeri* to the annual mean temperature underscores the species' sensitivity to climate change, hence reflecting broader concerns regarding the impact of global warming on amphibian populations. Additionally, annual precipitation is another important factor that indicates the essential requirement for moisture by amphibians. Due to their permeable skin, these organisms rely on a moist environment to facilitate gas exchange (Harvey Pough, 2007). This unique physiological trait makes them highly susceptible to fluctuations in moisture levels within their habitat (Harvey Pough, 2007; Lips et al., 2003; Stuart et al., 2004). The study conducted by Mi et al. (2022) clearly illustrates the correlation between precipitation patterns and the availability of suitable habitats for amphibians, showing that the average annual precipitation had the greatest impact on the spatial distribution pattern. Based on the model, the reliance of *P. stejnegeri* on the annual precipitation factor further demonstrates the complex interplay between amphibians and their hydrological habitats. Lastly, elevation was found to be a significant factor for *P. stejnegeri*'s distribution. It has been proposed that elevation affects the local weather conditions, which, in turn, affects amphibian population diversity and dispersal. McCain and Grytnes (2010) demonstrate how elevation gradients influence biodiversity patterns, such as those of amphibians, by generating diverse ecological niches at different altitudes. The importance of elevation in *P. stejnegeri*'s distribution model emphasizes how changes in altitude can define the boundaries of acceptable habitats for amphibians, affecting their distributional range and population dynamics (Fu et al., 2006; Supsup et al., 2022). Overall, the model's ability to accurately predict the current distribution of *P. stejnegeri* suggests that the species is highly influenced by a range of climatic and topographic parameters, specifically temperature, precipitation, and elevation. This highlights the crucial significance of these environmental conditions in the conservation of this species.

According to future climate projections, it is predicted that the range of *P. stejnegeri* would see substantial changes, with a large reduction in appropriate habitats, especially under the high-emission scenario (RCP 8.5). This estimate is consistent with the global consensus on the anticipated effects of climate change on biodiversity suggesting that several species would have reduced habitats because changing climatic conditions (Bellard et al., 2012; Blaustein et al., 2010; Chen et al., 2011). The model forecasts a significant decrease in the spatial range of *P. stejnegeri* under both RCP 2.6 and RCP 8.5 scenarios, highlighting the severe threats that climate change poses to its habitat suitability. The range contractions in the northern part of Mindanao are particularly noteworthy, suggesting that these areas may no longer be suitable for the species due to shifts in climatic conditions. The anticipated decrease in habitat in Mindanao could have significant implications for the population of *P. stejnegeri*, given that this species is endemic to the island. The projected changes in the distribution of *P. stejnegeri* emphasize the broader challenges that endemic species in biodiversity hotspots are facing because of climate change (Trew and Maclean, 2021). In light of these concerns,
potential strategies could involve habitat restoration, the creation of biological corridors, and the safeguarding of climate refuges that may remain suitable amidst changing conditions (Rahman et al., 2019; IUCN SSC Amphibian Specialist Group, 2020). The establishment of corridors will be useful in linking habitats and refuges of *P. stejnegeri* that are expected to remain viable under future climate scenarios. This will facilitate the movement of the species to more suitable environments and is crucial for its adaptation to environmental changes (Beier, 2012).

**Conclusion**

This study models the habitat suitability and distribution of *P. stejnegeri* under both current and projected future climate scenarios using MaxEnt. The study determined that annual mean temperature, elevation, and yearly precipitation are the main factors affecting *P. stejnegeri*’s distribution. Future projections demonstrate the vulnerability of *P. stejnegeri* to climate change, highlighting a substantial decrease in its geographical range under both mild (RCP 2.6) and severe (RCP 8.5) future climate conditions. The reduction in range, specifically in the high-emission RCP 8.5 scenario, emphasizes the pressing risk that climate change poses to the species. Given the species' sensitivity to environmental factors such as temperature and precipitation, together with the projected decrease in geographical range due to climate change, it is important for conservation efforts to prioritize the adaptability and quality of *P. stejnegeri*’s habitats.

**References**


Román-Palacios, C. and Wiens, J.J. (2020). Recent responses to climate change reveal the drivers of species extinction and survival. *Proceedings of the National


Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)
This article is 100% contributed by the sole author. He conceived and designed the research or analysis, collected the data, contributed to data analysis and interpretation, wrote the article, performed critical revision of the article, edited the article, and supervised and administered the field work.

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Research involving human bodies or organs or tissues (Helsinki Declaration)
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