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Utilization of Marginal Water and Lands in the Zeravshan River Basin as Part of a Climate Change Adaptation Strategy

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Abstract: This paper considers how marginal mineralized waters and salt affected soils can contribute to land remediation and create additional nutrition values for livestock and agropastoral communities through cultivation of arid/semiarid salt loving plants (halophytes) under water scarcity conditions. The mobility of toxic pollutants is highly facilitated by both chemical properties of soils and the aridity of the climate. Plants under such environments face multiple stresses caused by high temperatures, water and soil salinity, heavy metals, high PH and long-term water-shortage. There are limited numbers of native species along Zeravshan River Basin able to establish themselves in these soils and produce palatable biomass. Being irrigated with low quality drainage and thermal artesian water, species of the genera *Artemisia*, *Climacoptera*, *Alhagi*, *Glycyrrhiza* and *Kochia* exhibited clear distribution patterns and their abundance and yield of green biomass varied significantly along salinity and aridity climatic gradients. The limits of mineralization of the marginal water optimum for crops growth and green biomass accumulation were found to be varied in the range of 2000-8200 mg l^{-1}. The soil salinity at the root zone was about 45 dS m^{-1} and salinity level of the ground water was 8.0-16.5 dS m^{-1}, inappropriate for the irrigation of traditional agricultural crops. A monitoring system for controlling interaction of chemical content of non-conventional irrigation water and salt affected soils through plants above-ground biomass over several sites in downstream area of Zeravshan river flow was established. Alternative use of marginal water and lands play a significant role in further development of climate change adaptation strategy leading to produce autumn-winter forage and improve the feeding system for livestock, thus diversifying animal products and incomes of local agropastoral communities by ensuring sustainable ecosystem function and resilience.

Key Words: Climate change, Land remediation, Marginal waters, Water quality, Zeravshan River

1. Introduction

Central Asia (CA) with its landlocked landscape, dry continental climate, and water scarcity, is greatly vulnerable to climate variability and drought. Climate change in CA had been reported to have above average temperature increasing trend over last 70 years equal to 1.2-2.1°C, which doubles the global average of 0.5°C (IPCC, 2007). Such warming poses a threat to the glaciers and snow storage that currently provide over 90% of the water for irrigation in summer season (Hagg *et al*., 2007). Observation of the glaciers over the last decades has already shown high recession rates (Aizen *et al*., 1997) and according to different climatic scenarios it will be accelerated over the next 20 years leading to reduction of CA rivers streamflows (Agaltseva, 2002). Most future projections show a temperature increase of 3-4°C in CA, accompanied by precipitation decrease in summer and increase in winter. The major implications of predicted climatic change scenarios will be changes in seasonality of the runoff, mild winters, hotter and drier summers, with decreased available water (Bernauer and Siegfried, 2012). Sommer *et al*. (2013) argue that southern CA could suffer the biggest hit to crop productivity due to seasonality changes and water availability. Reduction in crop yields and agricultural productivity are key climate change impacts on CA dryland agro-ecosystems, with subsequent threats to the food security in the region. At the same time CA dryland ecosystems have faced severe (large-scale) water quality deterioration and land degradation caused mostly by soil salinity and loss of crop productivity due to water overuse (Toderich *et al*., 2005, 2013). Therefore, the current debates of climate change impacts on socio-ecological systems are oriented towards developing strategies for adaptation to the expected adverse impacts and increased water stress.

Utilization of both marginal waters and lands under a climate change water scarcity scenario can be a potential way of addressing forage availability for livestock and creating additional nutrition from pastures on marginal lands that will suffer the biggest hit under decreased amount of available water. There is little or no information on utilization of low

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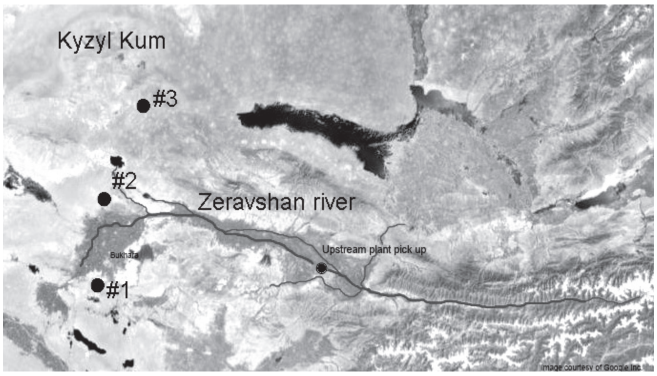

Fig. 1. Zeravshan river basin and research sites (source: Google Maps).

quality water and salinized lands for alternative agriculture use in CA, even though developing such techniques would be clearly advantageous, as such lands are underused, and these methodologies would not be in any competition with already existing farming practices.

The goal of this study is 1) to develop techniques of adaptation and remediation of polluted areas by using native salt tolerant plant species, and utilizing low-quality water; 2) conduct chemical analysis of plants along Zeravshan river basin; 3) to address desertification problems and suggest solutions for diversifying forage sources for the livestock and ensure ecosystem enrichment and function.

2. Methods and Strategy

In this research several experimental sites were setup to study remediation strategies using salt tolerant plants under extreme dry climate conditions. The study is based on the use of mineralized drainage waters in the lower Zeravshan River basin sites and an additional site in the Kyzyl Kum desert (**Fig. 1**). Two sites, #1 and #2, are situated in the Bukhara oasis, lower river basin and were established outside of the traditional irrigation areas, mostly on high salinity lands with brackish water flow, to assess impact of polluted waters on plants. Site #3 was established in Kyzylkesek (Central Kyzyl Kum desert) to check adaptation to extreme climatic conditions. It is characterized by higher temperature variation and much drier conditions compared to the Bukhara oasis sites, and there is no direct access to the fresh water, but there is an available mineralized artesian thermal water source. According to the Uzbek Meteorological Agency, temperature at this site is on average 2-3°C higher compared to Bukhara oasis. To monitor climatic conditions, a meteorological station measuring wind speed, air temperature, humidity, and other related parameters was installed.

Marginal waters obtained from the collector drainage system for research sites #1 and #2, and artesian mineralized, thermal water for site #3 were applied for crop irrigation. Water quality and level of mineralization was assessed through several annual measurements on sites, showing relatively same level of mineralization (Toderich *et al*., 2013). Salt tolerant tree and shrub seedlings on sites #1 and #2 were deeply planted (roots tapping into the water table) in the early spring or late autumn, and irrigated once with low quality water in the initial stage of growth, before the seedlings are able to utilize the available groundwater resources. On site #3 plants were irrigated once in July. Growth rates and forage yield with and without irrigation, as well as water and soil chemistry characteristics were measured regularly. To assess soil and chemical influence on the experimental plants, chemical analysis was also done on plants growing upstream as a control. Plant materials were collected in the hottest season (July-August), dried at 105ºC for 24 hours, and pulverized before the chemical analysis. The same plants species from upstream and downstream were used, to compare results. Plant ash for analysis was prepared by burning dry plant biomass in melting pots under 600ºC for 1 hour. Element analysis was conducted using Varian Atomic Absorption Spectrophotometer AA240FS standard method.

3. Results and Discussion

Zeravshan is a transboundary river in Central Asia that has been profoundly affected by mismanagement of the water resources due to the huge diversion of water for irrigation, poor functioning and maintenance of the drainage networks, as well as high rates of water loss. The region relies on conventional furrow and flooding irrigation practices and soil leaching that requires large amounts of water, and although the Zeravshan River is fully utilized for irrigation, that is still not enough to cover irrigation needs, even though 20% of the runoff water is reused. It was estimated that 12% of the irrigated lands are classified as highly saline and 33% as medium saline, requiring more water to leach the salts from the soil before planting (MAWR, 2004). The mobility of toxic pollutants was highly facilitated by both chemical properties of soils and the aridity of the climate. Under such environmental conditions plants face multiple stresses caused by high temperatures, soil salinity, heavy metals, compacted soil, and long-term water shortage. A restricted numbers of salt tolerate plants (halophytes) able to survive and reproduce well under extremely conditions were identified as a result of this study. They are mostly wild grown native species from the genera *Salsola*, *Artemisia*, *Tamarisk*, *Glychyrrhiza*, *Alhagi* and others, which are suitable as livestock forage, bioenergy and other sources of income.

3.1. Plant growth and adaptation to extreme conditions

Measurements of soil EC at the beginning and the end of

Table 1. Plant growth and yield of palatable biomass on the research site #3.

Name of species	Yield of biomass, t/ha		Days of
	Green	Dry	vegetation
Climacoptera lanata	29.5± 4.6	15.5±7.1	160-190
Climacoptera lanata *	6.22± 2.1	1.15±0.6	210-235
Glychyrriza glabra	8.4±4.1	3.27 ±3.1	205-220
Glychyrriza glabra *	5.08-6.34	1.46-1.63	220-235
Salsola orientalis *	2.0-2.8	1.0-2.2	250-254
Alhagi pseudoalhagi *	1.24-2.40	0.85-1.60	218-225
Kochia prostrata *	2.6-3.09	2.06-2.16	250-260

*results with no irrigation applied

Fig. 2. Site #3 in July, naturally grown (left) and irrigated fields (right).

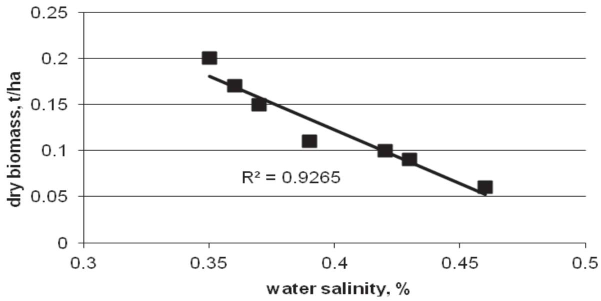

Fig. 3. Biomass variability over water salinity on Alhagi pseudoalhagi.

the vegetation season indicated that the soil was of medium salinity, although at the upper 40 cm horizon at some points EC reached values of over 25 dS m^{-1}. Most species exhibited clear distribution patterns and their abundance and biomass accumulation varied significantly along the salinity and aridity climatic gradients. The soil salinity at the root zone was about 45 dS m^{-1}, salinity level of the ground water was 8.0-16.5 dS m^{-1}, which is inappropriate for the irrigation of traditional agricultural crops however, this did not affect growth. Plants had tolerated the strong soil salinity without inhibition in survival and growth rate due to the sample soil moisture conditions provided by the groundwater and irrigation (although applied at deficit rates). The performance of investigated annual and perennial plants on saline soils and irrigated with marginal water shows high growth rates, comparable to those in agricultural irrigated land, although root-zone salinity slightly increased (**Table 1**). Due to low transpiration capacity, Alhagi pseudoalhagi communities grown near the experimental area helped in retaining soil moisture in the top soil. The results on site #1 were on average 10% higher compared to site #2, and site #3 saw a decrease in productivity of 30%. However, cultivated pastures showed promising results on site #3. Comparison of naturally grown with cultivated pastures in vicinity of site #3 is shown on **Figure 2**.

Although results show a promising potential of using marginal waters on already saline lands, it is important to emphasize that an upper limit of salt concentration in soil and water as well as in groundwater levels should be preserved and controlled. The fresh biomass of investigated species sharply decreased with the increasing gradient of soil salinity as shown on the **Figure 3**. The limits of mineralization of the marginal water optimum for crops growth and green biomass accumulation were found to be varied in the range of 2000-8200 mg l^{-1}. Above a certain threshold value, high total concentrations of salts are harmful to crop growth, while individual salts can disturb nutrient uptake or be toxic to plants. Not only that, some plants are noticeably sensitive to groundwater level rise, and for reclamation of waterlogged lands, appropriate species should be chosen. For example, Salsola L plant adaptation and growth decreased with increased water table level, and thus salinization.

3.2. Environment and soil remediation

Marginal lands and marginal water have great potential for utilization, creating an additional resource for the pastoral community under extreme dry and hot conditions. At the same time, the question of how plant chemistry would respond to the marginal water application was emphasized in our second research objective. Same species from upstream were compared with ones in the lower stream sites. Results have shown that salt and metals concentration in plant tissue increase from upstream to downstream, as demonstrated clearly by the *Tamarix hispida* chemical ions content (**Fig. 4**). Concentrations of calcium, bicarbonate, sodium, and chlorine rise significantly to downstream, showing noticeable correlation with water quality conducted in previous research (Khujanazarov *et al*., 2012). These pollutants are released into the lower part of Zeravshan River from numerous sources in upstream, and are accumulated and/or excluded by plants. Compared to other regions in Uzbekistan, plants in the Bukhara oasis show relatively high concentrations of heavy metals (**Fig. 5**), especially noticeable in *Artemisia diffusa* and *Salsola* L. Similarly high salt ion content was found in the aboveground biomass of *Tamarix hispida* (Fig. 5), demonstrating

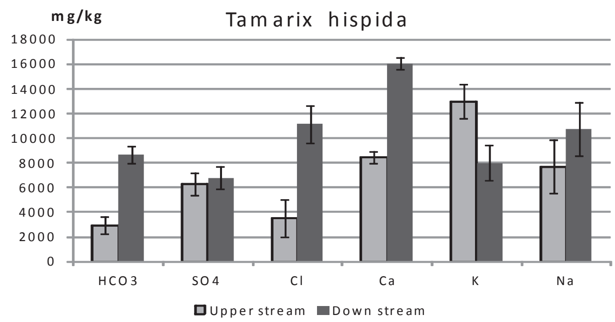

Fig. 4. Chemical mineral content of Tamarix hispida along river.

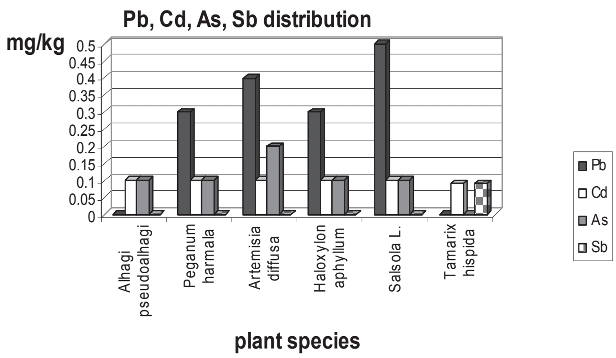

Fig. 5. Native desert plants species able to translocate heavy metals in above ground biomass.

its ability to selectively remove specific heavy metals and salts from soils. This ability of plants to uptake pollutants from affected soil must be incorporated into alternative solutions for remediation of polluted lands. Therefore non-conventional waters can be used in conjunction with crops conservation practices designed to remove metals and salts from contaminated environments. By implementing these methods and processes, there is the added benefit of reducing waste discharge and thereby improving water quality within the catchments as well as decreasing water stress and adapting to limited water availability.

4. Conclusion

Our findings show how plants interact with water and soil environments to adapt and cope with high concentrations of nutrients and toxicants which occur naturally or as pollutants. Experimental sites on saline soils demonstrated promising results for potential utilization of marginal waters with limited irrigation for agropastoral use. Additionally, these species could be used not only for land rehabilitation and reducing carbonate salts and heavy metals concentration in soils, but also for biological restoration and enrichment of the surrounding agro-ecosystem. Planting halophytes has proved to be effective in re-vegetating saline landscapes, deriving valuable products from marginal degraded land, and making use of the otherwise low quality water, under conditions of heat, dryness, and high evaporation rates. However, care needs to be taken and monitoring systems should be in place to ensure proper management of marginal water and lands.

This could be an effective strategy in dealing with future climate change conditions and water scarcity in Central Asian desert environments, and address human employment in pastoral lands. Through our research it was possible not only to address land rehabilitation issues, but also increase the knowledge base of the Zeravshan River basin, by sharing these results with the public (Khujanazarov, 2012).

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