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Climate Change Impact and Environment Adaptation in Zeravshan River Basin

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Synopsis

We investigated impact of climate change on the Zeravshan river basin and applicable adaptation measures for the future development in the region. This study is focused on two major goals; the first predicting future flow conditions and the second is measures to operate marginal waters in the downstream under future decreased flow condition. Land-surface model SiBUC future projections show a flow increase, accompanied by precipitation decrease in summer and increase in winter. Water availability in late summer will become the main issue as well as changes in seasonality of the runoff and higher temperatures. In the second topic marginal waters potential and quantity calculations has been researched to address water availability in Zeravshan River Basin under climate change impacts. Findings show how plants interact with water and soil environments under stressed conditions. Utilization of both marginal waters and lands under a climate change water scarcity scenario can be a potential way of addressing forage availability without requiring fresh waters from river and improving environment.

Keywords: climate change, SiBUC, adaptation strategies, marginal waters, water management, Zeravshan river basin

1. Introduction

Zeravshan is a transboundary river in Central Asia that has been profoundly affected by mismanagement of the water resources due to the huge diversion for irrigation, poor functioning and maintenance of the drainage networks, as well as high rates of water losses (fig. 1). The region relies on conventional flooding irrigation practices and soil leaching that requires large amounts of water. Although, Zeravshan river is fully utilized for irrigation use that is still not enough to cover irrigation needs, even though 20% of return water is reused again. On the other hand, excessive and mostly uncontrolled use of water for irrigation coupled with poor drainage collector system caused large-scale land degradation and water quality deterioration, mostly expressed in downstream areas (Toderich et al, 2005). Soviet cotton production race has increased water pollution that salinized vast irrigation and pastoral lands in downstream area. According to the official data from the (MAWR, 2004) 12% of the irrigated lands are classified as highly saline and 33% as medium saline, requiring each time more water for cleaning soils before planting. These processes may be intensified by climate change under less water availability and frequent droughts in Central Asia directly impacting human wellbeing (Toderich et al, 2010).

Indeed climate change can become a major challenge to the Central Asian countries, especially in dry season. Central Asia had been reported to have above average temperature increasing trend equal to 1.2-2.1°C, which doubles global average of 0.5°C (IPCC, 2007). Most future projections shows temperature increase to the rate of 3-4°C in Central Asia, accompanied with decrease in precipitation amount in summer and increase in winter. Such warming poses a threat to the glaciers and snow storage that currently provides 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 (Agaltseva, 2002). Bernauer and Siegfried (2012) suggest the major implications of the predicted climatic change scenarios will be changes in seasonality of the runoff, mild winters, hot and more dry summers with less amounts of available water. Such climate change is accepted to have great impact not only to agriculture due to water availability and quality deterioration caused by lesser water availability but also cattle breeding in directly affecting forage availability and other spheres of human activities in region. It is also important to note continuous arguments between countries sharing river (Tajikistan and Uzbekistan) about river operation. Tajikistan as a country generating 95% and using only 4% of the river flow is expecting to expand its operation on it. On the other end Uzbekistan currently using 100% of the incoming flow could be faced with serious consequences in the most densely populated agricultural region if this scenario will be developed. Thus developing alternative scenarios for water resources assessment and usage is important.

Climate change and water scarcity can make the marginal (low quality) and return flow (drainage, sewage) that is not fully utilized water a potential source for irrigation or technical use to address forage availability for the pastures in dry and hot conditions or land remediation. Several our studies focused on the use of salty water in the non traditional manner for agriculture gave promising results (Toderich et al, 2010, Khujanazarov et al, 2014). Although, usage of such waters can increase soil pollution recent studies showed potential of sustainable utilization of marginal water resources for irrigated agriculture and other needs of local rural communities (Saito, 2010). Potential of the marginal water usage is especially high in Uzbekistan, where about 95 percent of this water comes from collector-drainage and the rest is municipal and industrial wastewater. Creating additional source of nutrition for agro pastures from salt-tolerated plants that can survive extreme conditions could be solution to address future climate change and water shortage as well as to address strategies to improve environment and human activities in regions that already suffers from dry hot summers and available water resources including future implications. Study on remediation strategies and adaptation measures to address future shortage of water in extreme conditions are important factor for the agriculture and economic growth ensuring food security in the region.

The goal of this study is 1) to show results of climate change impact through simulation by land surface model SiBUC in the Zeravshan river basin, and 2) to develop techniques for adaptation and remediation of the highly polluted areas through local salt tolerant plant species. It can help to address water shortage, desertification problems, provides forage source for the pastures and improve environmental conditions in the region.

Fig. 1 Zeravshan river basin study area (source: Google Inc)

2. Methodology

2.1 SiBUC model set up and datasets

To address climate change impact and assess river flow change we applied Simple Biosphere model including Urban Canopy (SiBUC) land surface model (Tanaka et al, 2004). The model use "mosaic" approach to incorporate all kind of land-use into land surface (fig. 2). In the SiBUC model, the surface of each grid area is divided into three land-use categories and five components. The model helps to analyze water balance in the basin and analyze impact of the climate change.

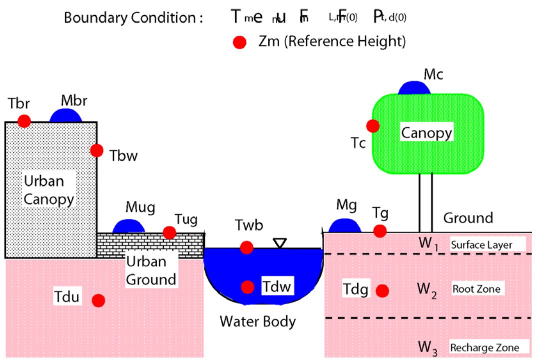

Fig. 2 Surface elements in SiBUC

In this study data from SRTM30 digital elevation data of CGIAR-CSI (Consultative Group for International Agriculture Research-Consortium for Spatial Information) was used (http://srtm.csi.cgiar.org) shown on figure 3. The data were analyzed from 250m resolution originally, additionally upscaled dataset of 1 km were used. Land use data of GLCC ver. 2 (global land cover characterization) by USGS grouped to 24 types were applied (fig. 4). We also obtained official irrigation area data from the Ministry of Melioration and Water Resources of Uzbekistan (MAWR). Spot Percentage of the land use area was calculated in each grid of 5km grid to re-classify the definition of land use in SiBUC in respect to non-irrigated area. EcoCliMap data needed for processing of the land surface process such as soil data rate, the number of leaf area, green leaves amount and other by (http://www.cnrm.meteo.fr/gmme/PROJECTS/ECOCLIMAP/page_ecoclimap.hrm) also were used.

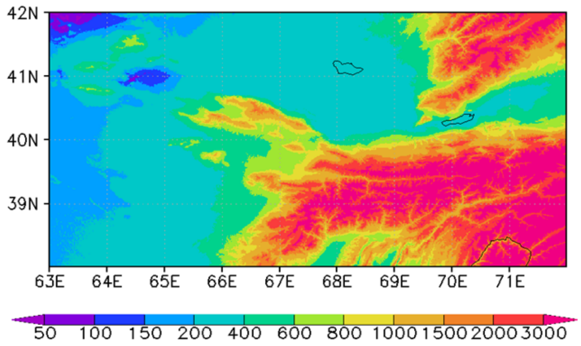

Fig. 3 DEM altitude output of the basin

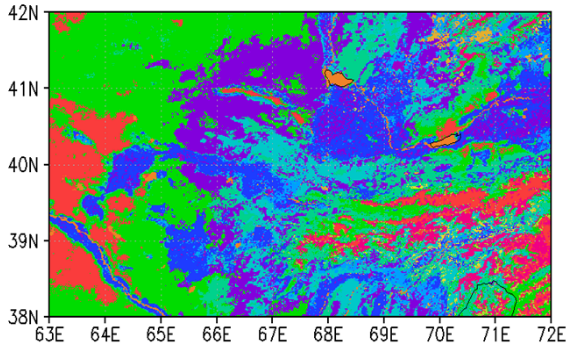

Fig. 4 Land uses classed by GLCC

Meteorological forcing dataset from Hirabayashi (H08) available for global use were chosen in this research. H08 dataset is weather data of 0.5° global by Hirabayashi et al. (2008) for 1948 to 2006 years provided for each day. The list of parameters include precipitation, snowfall, shortwave radiation, specific humidity data of each day, the temperature and long-wave radiation of every three hours. In addition to meteorological data that has been forced from the observational data, we also corrected coverage of the rain gauge data using the wind speed data in H08 in Central Asia due to dependency to water source in snowfall in areas of high altitude. Additionally data from JRA-25 (http://jra.kishou.go.jp/JRA-25/index.html) to supply atmospheric pressure and wind velocity missed in H08 were analyzed. Hydrological observed daily dataset from Meteorological Agency of Uzbekistan collected from 1959 to 1999 of the river discharge were used to check river flow historically and calibrate river flow output. Future simulation using GCM datasets (MRI-AGCM3.2S) were divided for near future in 2030 to 2050 and further from 2050 to 2099.

2.2 Marginal waters potential analysis

Study on adaptation to the water pollution on soils and plants impact to study remediation strategy of salt tolerant plants to extreme climatic conditions were setup on experimental sites. Two sites (in Bukhara oasis, the river downstream) were established outside of the traditional irrigation areas, mostly high salinated lands with brackish water flow to assess impact of polluted waters on plants and one site to check adaptation to the extreme climatic conditions (dry, high temperatures, far from fresh water sources) in Kyzyl Kum desert with available mineralized artesian water (fig. 1). The site in Kyzyl Kum desert is characterized with higher temperatures variations and much dryer conditions compared to Bukhara oasis, there is no direct access to the fresh water, only thermal artesian well abo100m deep. According to Uzbek Meteorological Agency temperatures in the selected area in Kyzyl Kum is on average 2-3°C high compared to Bukhara oasis. To control climate conditions meteorological station measuring wind speed, air temperature, humidity and others were installed. Plant adaptation to such severe climatic conditions could support usage of the selected plants for possible climatic change.

There is little or no information on utilization of low quality water and salt affected lands for alternative agriculture use. Even though such categories of water and lands are no (in)direct competition with food production or other uses. We had applied marginal waters from collector drainage system for research sites in Bukhara oasis and artesian mineralized water source in Kyzyl Kum were used for the site #3. Water quality on mineralization was assessed through several annual measurements on sites.

Plants under such environments face multiple stresses caused by high soil salinity, heavy metals, organic pollutants, high pH, impenetrable soil, long-term water-shortage that will be exaggerated in climate change. As such plants that can survive soil and water mineralization as well as extreme dry and high temperatures conditions should be selected. Several plants had proved to be able to survive and reproduce under salt contaminated environments figure 5. Trees and shrubs seedlings were deeply planted (sticks tap into the water table) in early spring or late autumn seasons and irrigated once with low quality water in the initial stage before the trees/shrubs can rely on the available groundwater resources on sites #1and #2. On site #3 plants were additionally irrigated in July. Grows rates, as well forage output and low quality water response were through seasonal measurements. To assess soil and chemical influence to the plants chemical analysis of the upstream as a control measurement were compared.

Through the first topic we could estimate available water for re-use in future that could be helpful in planning further activities and the second topic addresses outcomes of the plant adaptation to extreme condition by using waste waters.

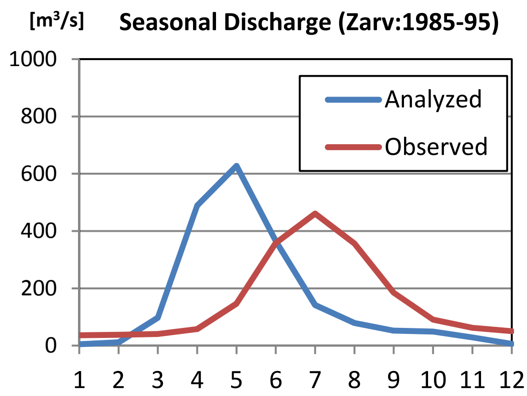

Fig. 5 Simulation of the discharge within a year

3. Results and discussion

3.1 Simulation inputs

The simulation in the upstream by SiBUC supported to have difficulties in the mountainous area and glacier feed river. Due to absence of the recent classified glacier data, high elevation over 4500m were proposed to have glacier coverage. This assumption further was checked by glacier coverage map available in the basin by Meteorological Agency of Uzbekistan for the year 2000. GCM datasets were subjected to BIAS correction for the area. The basin was divided to 4 areas: upstream - mountainous areas, irrigated areas in downstream, non-irrigated areas and areas above 100 meters and others. Correcting coefficient were used to match observed datasets in 1972-2000 years. It is also important to mention that SiBUC has shown great potential to reproduce water balance in the region. The impact of the flow were analyzed compared to the data on Dupuli station in the upstream (fig. 1).

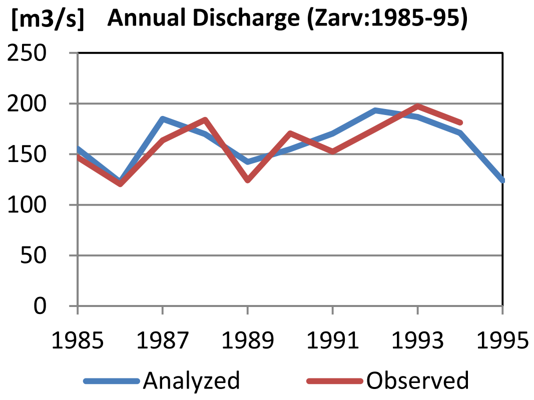

Fig. 6 Average water balance for whole year

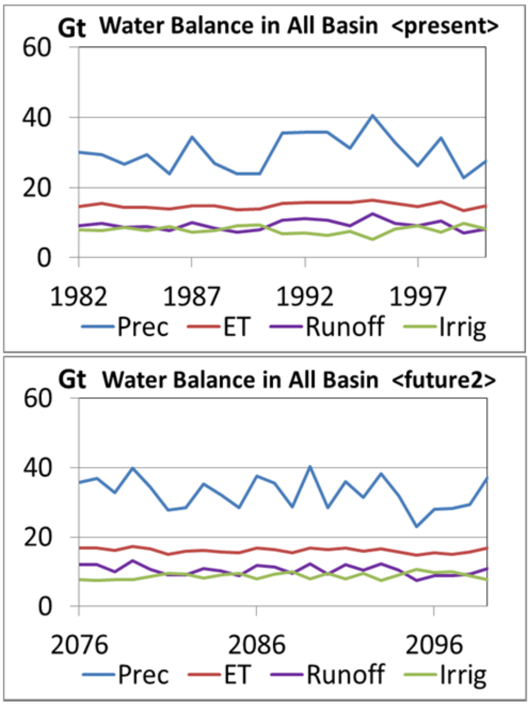

Fig. 7 Water balance in whole basin.

Results of simulation has shown reasonable outcomes, however the peak flow is shifted to the earlier period compared to observed dataset (fig. 5). This is result of possible errors in the forcing dataset (high wind speed and air pressure) or special climatic conditions in the steep mountains of the Zeravshan River George. Although compared to the average annual discharge simulation results are not significantly different from observed (fig. 6). We concluded that total available water flow stays reasonably close to observed data to make further flow estimation.

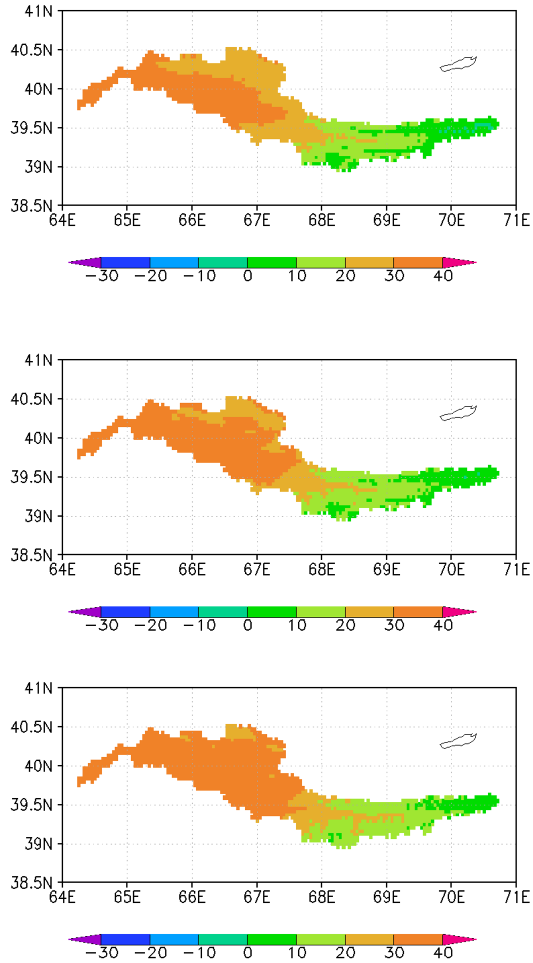

Fig. 8 Comparison of the temperatures in July.
a) present; b) average for 2030-2050; c) future average 2050-2099

It is important to address earlier water peaks on the river with further analysis of the glacier melting and river basin topography for altitude dependant correction proved to be one of main factor in the simulation overestimation. Overall results show that water discharge will increase by 10% in future climatic conditions (fig. 7). Additionally summer will have more rise in temperatures leading to the shortage in the irrigation water (fig. 8) due to high evapotranspiration rates and glacier melt. We also conclude that precipitation will be increased in the upstream but will significantly reduced in the downstream. Current water availability from glacier can be changed to the snow melting, due to rise of temperatures in winter months. This hypothesis will have to be proved for the future research.

3.2 Plant grows and adaptation to extreme conditions

Simulated results and reviewed literature for past years has shown growing rates in the temperature and decrease in available water in most hot and dry times of the year. Such outcomes could be very sensible for the irrigation in Uzbekistan. We had used the strategy to find possible solutions on re-use of the water in the stressed conditions to address current needs of the local community which also can be applied in future.

Bukhara oasis vegetation contains restricted number of species, with metal/salts removal and successful reproduction abilities under contaminated environments. These important properties could address desertification issues as well as climate change impacts of drying, high evapotranspiration rates, water availability and soil erosion to fix salt spreading through sand storms at the same time in the south-eastern Kyzyl Kum desert and settlements.

Several sites picked in this research are stated on the salted lands and haven't been used for irrigation practices. 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} inappropriate for the irrigation of local agricultural crops, however, this did not affect growth. The performance of the trees and shrubs in saline soils and irrigated with marginal water shows high growth rates, comparable to those in irrigated land, although root-zone salinity increased. Measurements of soil EC at the beginning and the end of the vegetation season indicated that the soil was of slight to medium salinity, although at the upper 40cm horizon at some points EC reached values of over 25 dS/m^{-1}. Most species exhibited clear distribution patterns and their abundance varied significantly along salinity and aridity climatic gradient. 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 (Khujanazarov et al, 2014). Due to low transpiration capacity, plants 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 9.

Fig. 9 Comparison in July, naturally grown (left) and irrigated lands (right) source: (Khujanazarov et al, 2014)

Although the results shows a great potential of using marginal waters on already saline lands it is important to emphasize that limits of salt concentration in soil and water as well as groundwater levels should be preserved and controlled. The fresh biomass of investigated species sharply decreased with the increasing gradient of soil salinity. 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.

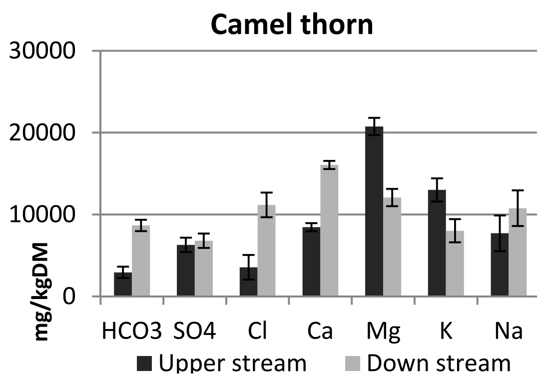

Fig. 10 Comparison of chemical content in upstream and downstream for Camel thorn

Our findings shown how plants interact with water and soil environments to adapt and cope with the enormous concentration ranges in nutrients, ions, and toxicants which occur naturally or as pollutants. Set up plots on saline prone soils have showed promising results on using marginal waters on limited irrigation for agropastoral use. Perennial tress/shrubs biomass production on degraded and marginal land can also improve soil fertility, and reduce other soil degradation processes such as soil erosion, leaching as a result of above and belowground biomass growth (Schubert et al., 2009). Moreover, perennial bioenergy crops cultivated on degraded and marginal land can increase the quantity and variability of biodiversity, especially if monoculture and large fields are avoided. On the other hand, these species could be used not only for land rehabilitation but also for reducing carbonate salts and heavy metals concentration in soils as well as rehabilitation of the surrounding environment and biomass production as shown on the figure 10 of Camel thorn plant chemical content difference compared to upstream and downstream. Through these researches it was possible to address land rehabilitation issues and increase knowledge base of the Zeravshan river basin.

4. Conclusions

Through findings of the SiBUC model simulation we conclude water flow impact of the future conditions and rise in temperatures in the basin. It is also possible to find irrigation needs in connection with the flow to estimate amount of available marginal or return flow water. As it was shown in the second topic they can be used for the land remediation or creating forage food for the cattle breeding or even bioenergy production. Such estimation could become important in future resource planning.

Additionally we have shown how plants interact with water and soil environments to adapt and cope with the enormous concentration ranges in nutrients, ions, and toxicants which occur naturally or as pollutants. It has proved to be effective in re-vegetating saline landscapes, providing valuable products to local agropastoral communities from marginal degraded land, and make use of the otherwise low quality water, unproductive lands,sustaining very dry and high evaporation rates. This could be an effective strategy in dealing with future climate change conditions and water scarcity in Central Asian desert environment, address human employment in pastoral lands.

It is also important to mention that SiBUC has shown great potential to reproduce water balance in the region. Although result show promising, there are still many shortcomings as of early high peaks of river flow, availability of the data and reliability of the model. This should be addressed in future research and to re-estimate water resources in the basin.

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