Emerald Books Volume on "Climate Change Modeling for Local Adaptation in the Hindu Kush-Himalayan Region"

Title - Assessing the Hydrological impact of Climate Change for the Amu Darya River, Afghanistan

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Abstract

It is now established by the global scientific community that climate change is hard reality but the changes are complex in nature and to great extent uncertain to predict. The classical global circulation models (GCM's) have made significant contributions to the theoretical understanding of potential climate impacts, their deficiencies soon became apparent. GCMs demonstrate a significant skill at the continental and hemispheric spatial scales and incorporate a large proportion of the complexity of the global system; they are, however, inherently unable to represent local sub grid-scale features and dynamics. The first generation approaches of climate change vulnerability assessment are derived from GCMs downscaled to regional scenario or local scales but the downscaled models are simplified versions of the climate of the locality, and have commonly been limited to changes in mean temperature, rainfall, and sea level. The hydrological response due to change in climate variables in Amu Darya River basin was investigated using Soil and Water Assessment Tool (SWAT). The modelling results show that there is increase in precipitation, maximum and minimum temperature, potential evapo-transpiration, surface run off, percolation and water yields. The above methodology can be practised in this region for developing adaptation and mitigation. This initial assessment will facilitate future simulation modelling application using SWAT to the Amu Darya River basin by including variables of local changes (e.g. population growth, deforestation) which affect directly the hydrology of a region.

Key Words; Climate change impact, Hydrological modelling, SWAT, Vulnerability Assessment

1. Theoretical Background

The scientific community all around the world put to rest any lingering doubts about variability to climatic change and their impacts reflected globally as well as regionally. The changes are in terms of climatic variables like change in precipitations, temperature snow cover, sea level changes and change in patterns in atmospheric and oceanic circulations and changes are largely contributed by human activities (**IPCC, 2007).** The hydrological regimes are inextricably linked with climate and the prospect of global climatic variability has a serious implication for both for process research and also catchment management strategies. Increased evaporation (due to high temperature), combined with low rainfall has potential effect to affect associated runoff, disappearance of streams and lakes in highlands, dwindling ground water stocks, water quality and pollution exacerbations are being felt both high land and low lying part of the world **(Royal Academic of Engineering, 2010).** The ability to analyze the impact of climate change on hydrology in Afghanistan and to develop effective mitigation and adaptation strategies is limited due to political instability in this region, weak formal and informal institutions, lack of long term time series climatic variables and observation on hydrological cycle with other constraints.

The climate science though requires projection, simulation, forecast and evaluation for predicting uncertain future but these global assessments are limited to their capacity to explain local and regional effect due to coarse spatial and temporal scale. The most credible tools available to simulating impact of global climate system to increasing green house gases in an unstable country like Afghanistan are General Circulation Models (GCMs). This method is able to simulate important climate variable at global scale. The first generation approaches of climate variability, vulnerability and adaptation are projected from Global Climate Models down scaled to regional scenario or local scales (**Carter et al., 1994; UNEP, 2000; Burton et al., 2002**). These GCMs are of limited value without appropriate down scaling technique for providing climate change information at local scale. Again these down scaled version of these models are also simplified version of the climate of the locality, and have commonly been limited to changes in mean temperature, rainfall, and sea level. The classical global models have made significant contributions to the theoretical understanding of potential climate impacts, their deficiencies soon became apparent. The second version is looking climate change from grassroots level. The current situation of instability juxtaposed with uncertainty of impact of climate change further limited the capacity to understand the changing scenario in these regions. The mass balance measurements done in HKH region were to measure of the health of a glacier and its ability to maintain its mass from one year to the next, the result do not reveal per se anything explicit about the hydrology of the basin containing the glacier. The studies regarding impact of glaciers melt on surface water supply in HKH region have primarily either qualitative or local in scale and in some case simply observation. The minimal change in volume of melt water from glaciers is not likely to have great effect to societies that adapted to current crisis of climate change.

2. Case study

The general impacts of climate change on water resources have been brought out by the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001) indicating an intensification of the global hydrological cycle and affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water based recreation. Global climate change due to enhanced greenhouse effect has emerged as one of the most pressing environment issues for the 21st century (Mirza and Ahmad, 2005). Emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases enhancing the natural greenhouse effect and resulting in an additional warming of the Earth‟s surface. The hydrological system is sensitive to changes in climate. The interactions between increases in greenhouse gases and hydrological system are very complex. Increases in temperature will result in changes in evapo-transpiration, soil moisture, and infiltration. Increased atmospheric CO2 may increase global mean precipitation as indicated by all GCMs. Changes in rainfall could affect water availability in soils, rivers and lakes, with implications for domestic and industrial water supplies, hydropower generation, and agricultural productivity. Increased evapo-transpiration enhances the water vapor content of the atmosphere and the greenhouse effect, and the global mean temperature rises even higher. Land use will also play a key role in increased evapo-transpiration. Possible changes in temperature, precipitation and evap-otranspiration may result in changes in soil moisture, ground water recharge and runoff could intensify flooding and droughts in various parts of the world (Mirza and Ahmad, 2007).

On this backdrop Amu Darya basin (shown in Fig – 1) which is considered as a case study and it covers 14 percent of the national territory, but alone it drains more than half (57 percent) of the total annual water flow of Afghanistan. The Amu Darya is formed by three major source rivers: the Panj originating in Afghanistan (Pamir and Wakhan rivers), the Murghab River also originating in Afghanistan and flowing into the Lake Sarez, then being called Bartang River, and the Vakhsh originating in Kyrgizstan (Kyzylsu River) as well as in Tajikistan (Muksu River). On its way to the

Aral Depression, only below the confluence of Panj and Vakhsh, the river is now called Amu Darya which is joint on its right bank by a few more tributary rivers (Yaksu and Karnifaghan in Tajikistan, and Surkhandarya in Uzbekistan), and on its left bank by Kokcha and Kunduz river in Afghanistan. The Amu Darya River (the classical Oxus River) runs for 2,400km and receives a large number of tributaries in Central Asia, but dries up in the Turan lowlands in Turkmenistan and Uzbekistan. The main reason for this is the excessive use of the water by irrigation for cotton production. Less than 20 years ago, the river ran as far as the Aral Sea. Today's lack of inflow has been a major factor for the dramatic reduction in the surface area and volume of the Aral Sea. Huge international efforts are presently being made by the UN, the World Bank and other donors to try to halt or improve the situation on the Aral Sea. Water availability in Amu Darya river Basin for multi purpose uses are mainly functions of valuable precipitation, evaporation, temperature, wind direction, solar radiation and surface as well as groundwater resources which depend in turn on the amount and distribution meanly (time and space) of water recourses. Therefore, considering variations in precipitation and snow fall are the most significant parameters. Water has very important role for socioeconomic activities and essential to maintain agricultural productivity which is the main sources of Afghanistan economy.

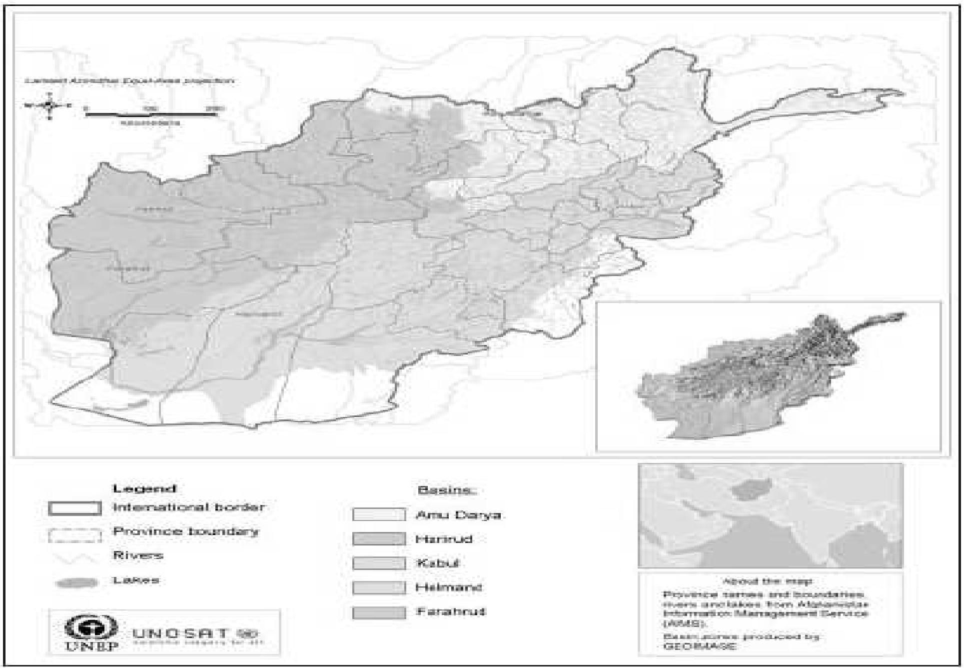

Fig. 1: Afghanistan water basins and river (Source: UNEP, 2003)

The land under cultivation in Afghanistan is limited and mostly located to the river bank and valleys. In north of Afghanistan the rain fed agriculture is found as predominantly, where temperatures are lower during summer and precipitation is adequate as to amount and reliability. On the high mountains, although precipitation is adequate, the potential for cropping is nevertheless limited by the frost-free period in these areas is short. In most location of Afghanistan, cropping is impossible without irrigation. Most of the country population lives in rural areas, and more than 85 % depend on

Agriculture and Animal husbandry. Three decades of conflicts, war, growing poverty and consequently years of drought forced some of the population to move from rural area to cities. The instability factor combined with component of uncertainty due to global climate variability reduce the coping ability of rural population in Afghanistan. Adaptation strategies are becoming more complex in HKH region as water managers navigate competing interests to reliably provide quality water to farms, businesses, and homes, while managing floods, protecting the environment, and complying with legal and regulatory requirements. The impact of climate change has already visible in irrigation and also water availability in the Amu Darya Basin. The changes in form of earlier snow melting spring floods increase in size and a shortage of water occurs in summer and early autumn increasing the risk of water shortages particularly in years of drought. It also enhances the water scarcity problem in this region **(Glantz, 2002; Masood & Wasiq, 2004)**. This river basin is one of the main production areas of Afghanistan. Although the above methodology can be widely practiced in this region for developing their adaptation, there are some limitations: (a) uncertainty resulting from the use of multiple GCMs, scenarios, downscaling models is seldom considered; (b) local changes (e.g. population growth, deforestation) which affect directly the hydrology of a region. Increasing consumption and the effective management of these existing resources should also given priority combined with relatively changes that may occur in either the climate or hydrology in the coming decades. Effective capacity-building requires a long-term commitment to address capacity gaps in knowledge generation and its dissemination, as well as in the processes that catalyze efforts to move from knowledge to action. The present paper review the different hydrological modelling technique available consequence climate change, their limitations, challenges and also propose different approach to deal with it.

3. Analysis of Climate Change Impact on different Hydrological Regimes; Modeling Techniques

The need of water in society and nature underscores the necessity to have clear understanding about the impact of global climate change on availability and variability of regional hydrological regimes. The impact of climate change on hydrological regime can be assessed by projections of climatic variables (precipitation, temperature and pressure) at planetary scale down scale to local hydrological variables. There still exists scale dilemma while assessing the impacts of climate change on different hydrological models **(Schulze, 1997).** The sciences of climate modelling and vulnerability assessment are developing rapidly in policy circles in order to choose adapted measures and policies to reduce vulnerability of water users and resources. The Global Circulation model provides overall information on the patterns of climate change, climate threats and key vulnerabilities. This method is able to simulate important climate variable at global scale. The first generation approaches of climate variability, vulnerability and adaptation are projected from Global Climate Models down scaled to regional scenario or local scales (Carter et al., 1994; UNEP, 2000; Burton et al., 2002). These GCMs are of limited value without appropriate down scaling technique for providing climate change information at local scale. Again these down scaled version of these models are also simplified version of the climate of the locality, and have commonly been limited to changes in mean temperature, rainfall, and sea level. The classical global models have made significant contributions to the theoretical understanding of potential climate impacts, their deficiencies soon became apparent. The second version is looking climate change from grassroots level. The current situation of instability juxtaposed with uncertainty of impact of climate change further limited the capacity to understand the changing scenario in these regions.

The Special Report on Emissions Scenarios (SRES) was prepared by the Intergovernmental Panel on Climate Change (IPCC) for the Third Assessment Report (TAR) in 2001 on future emission scenarios to be used for driving global circulation models to develop climate change scenarios. It was used to replace the IS92 scenarios used for the IPCC Second Assessment Report of 1995. The SRES Scenarios were also used for the Fourth Assessment Report (AR4) in 2007. These emissions scenarios are organized into families, which contain scenarios that are similar to each other in some respects. The six families of scenarios discussed in the IPCC's Third Assessment (TAR) and Fourth Assessment Report (AR4) are A1F1, A1B, A1T, A2, B1, and B2. For projections of climate change in the 21^{st} century, a subset of two IPCC-SRES scenarios (scenarios A2 and B1) has been selected from six families of scenarios and simulations have been made on them.

For this study, the observed (2004 – 2008), present model (2001 – 2010) and future model (2021 – 2050) water resources were simulated with the SWAT model using A1B and A2, scenarios and compared.

Following are the steps involved in the Hydrological modeling (SWAT):

- Digital Elevation Model (DEM): It was taken from the US. Geological Survey's (USGS, 2006) public domain geographic data base HYDRO1K of 1 Km resolution.
- Stream network was clipped from the Asian HYDRO1k data set whish was under six raster and two vector layers the
- River Basin network was clipped from Afghanistan watershed shapefiles sourced AIMS
- Soil database: Soil of study area was extracted from NRSC site. The characteristic of soil extracted using HWSD software figure 3.
- Land Use Land Cover Map of year 1992 was used in SWAT simulation and analysis. The LULC data sourced AIMS figure 4.

- Metrological data: Temperature, Precipitation, Wind speed, Solar Radiation, and Relative Humidity Data (daily time scale)
  - Daily observed date for period of year 2004 – 2008 and present data from model for year (2001 – 10) under selected scenarios (A1B and A2), and solid data from metrological deportment of Ministry of Water and Energy in Afghanistan.
  - Daily, monthly, and annual predicted data base on selected scenarios (A1B and A2) for period of year (2021 – 50): Source- CCCMA

DEM of Amu Darya River Basin in Afghanistan was loaded in the SWAT interface of Arc View and automatic delineation process was done. Defining the inlet and outlet point was the next step. Number of inlet points will determine the number of sub-basin (next spatial unit used in SWAT after watershed) within the watershed and it is totally dependent on the need and objective of the user. Outcomes layers and themes added to the project contain the parameters of the watershed(s) characterization. After this a complete report is added to the current project which gives the details of the elevation of the watershed and the sub-basins.

Once the watershed was delineated next step was to do HRU (hydrologic response unit) analysis, which represents unique combinations of land use and soil within the sub-basin of a particular watershed as shown in figure 5. This step allows the user to load land use and soil layers into the current project determine the land use/soil class combinations and distributions for the delineated watershed and each respective sub-watershed. Land Use and Soil Characterization for a watershed were performed using two commands in the Avswat menu of the Watershed View. The themes can be either grid or shape format.

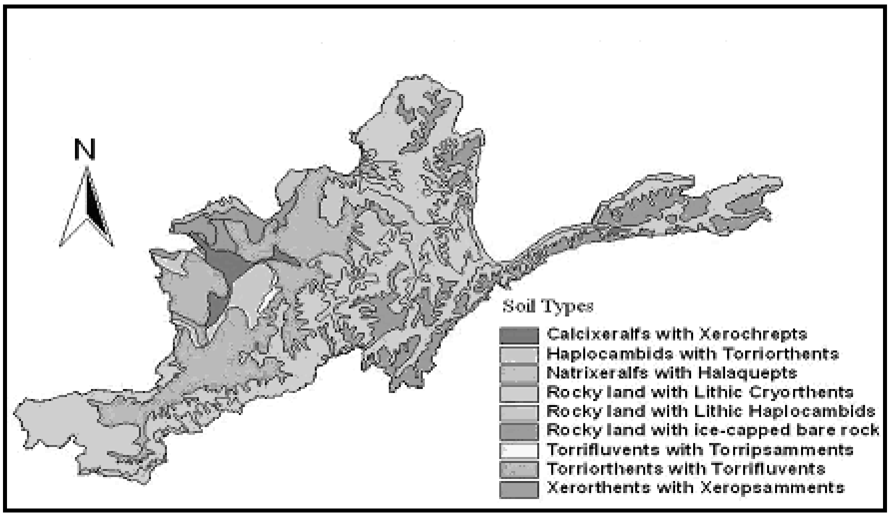

Fig. 3: Soil Type layout of Amu Darya River Basin in Afghanistan generated by SWAT

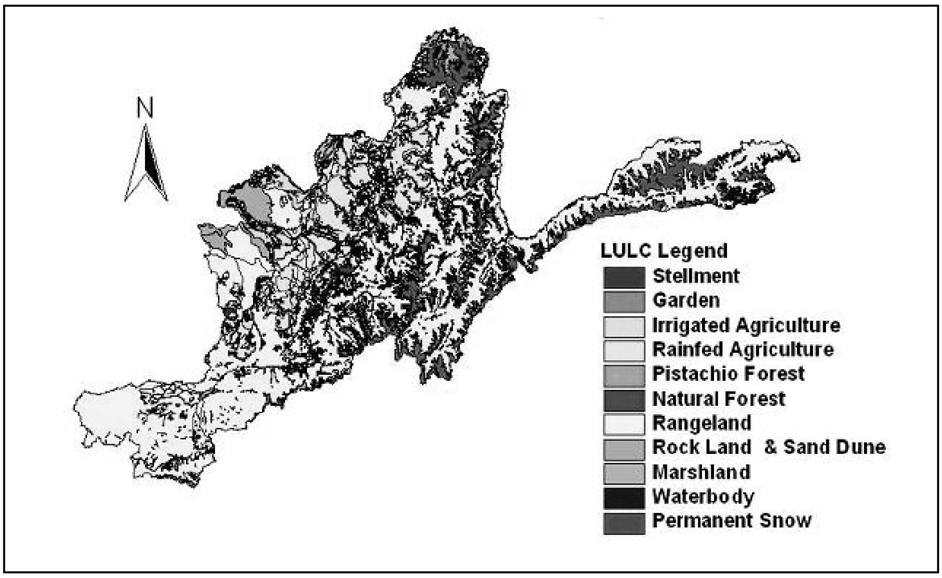

Fig.4: Land Use Land Cover of Amu Darya River Basin

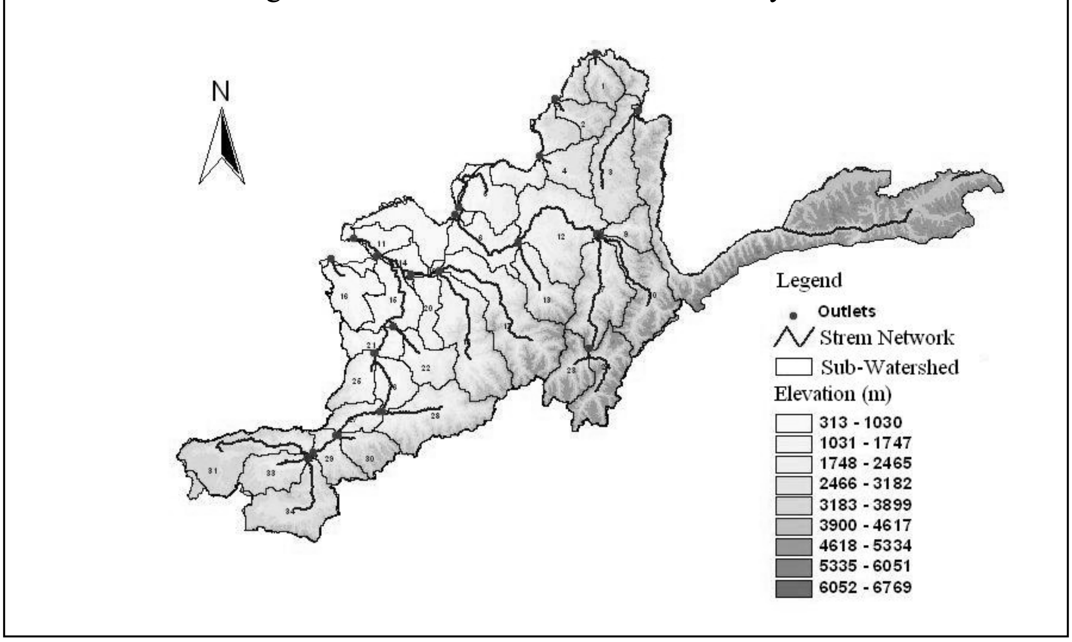

Fig. 5: Shows the Elevation, Stream Network, and sub watershed of Amu Darya River Basin in Afghanistan developed by SWAT

There are some limitations such as uncertainty resulting from the use of single GCM, two scenarios, downscaling models, availability of observed data, and no consideration to local changes (landuse change) which are important to study the hydrology and water balance study.

The Average of monthly Precipitation (PRECIP), Potential Evapotranspiration (PET), Evopratranspiration (ET), Peculation (PERC), Surface Runoff (SURQ) and Water Yield (WYLD) as simulated by the SWAT over the Amu Darya River Basin in Afghanistan for observed and SRES future scenarios A1B and A2 for periods of time is represented in Table(2).

Table 2: Annul Average Water Balance on Amu Darya River Basin in Afghanistan and Temperature of Region for Observed and Predicted Climate Change Scenario

Period	PRECIP	PET	ET	PERC	SURQ	WYLD	T-MIN	T-MAX
Observed(2004 - 08)	525.4	1132.0	210.8	67.4	82.1	298.2	7.96	22.60
Present Model (2001 – 10), A1B Scenario	525.5	1128.3	269.3	60.3	56.8	245.3	6.01	12.79
Present Model (2001 – 10), A2 Scenario	524.8	1129.5	275.5	58.4	54.1	240.8	6.01	12.79
Future Model (2021 – 50), A1B Scenario	540.6	1173.0	261.7	66.2	58.7	270.1	9.12	23.70
Future Model (2021 – 50), A2 Scenario	567.8	1173.5	269.6	69.6	69.6	290.1	9.17	23.74

Table 2 illustrates the following results for each water balance indicators:

- Precipitation (PRECIP): indicate an increase of around 30 mm depth of rainfall when compared with present model data. It is not significant increase and this can develop some stress in basin considering other demographic and development changes.
- Temperature: Analyzing of temperature of predicted future Scenarios with observed data indicate that there is change of 1.5 °C in minimum and 1.1 °C in maximum temperature in case of A1B scenario, while change of 1.6 °C in minimum and 1.2 °C in maximum temperature in A2 scenario as shown in fig. 6.
- Potential Evapotranspiration (PET): Indicates the high value in both the scenario i.e., A1B (2021–50) and A2 (2021–50) when compared with present model situation
- Percolation (PERC): Increase in percolation rate in future model scenarios compared to present scenario
- Surface Runoff (SURQ): Based on observed data from Table 2, there is also rise in surface runoff (around 25% of increase precipitation)
- Water Yield (WYLD)

  Highest value in observed data indicates that there is all other scenarios in decrease mode, while present model (2001 – 10) A2 scenarios point the lowest volume of water yield in the region under this study.

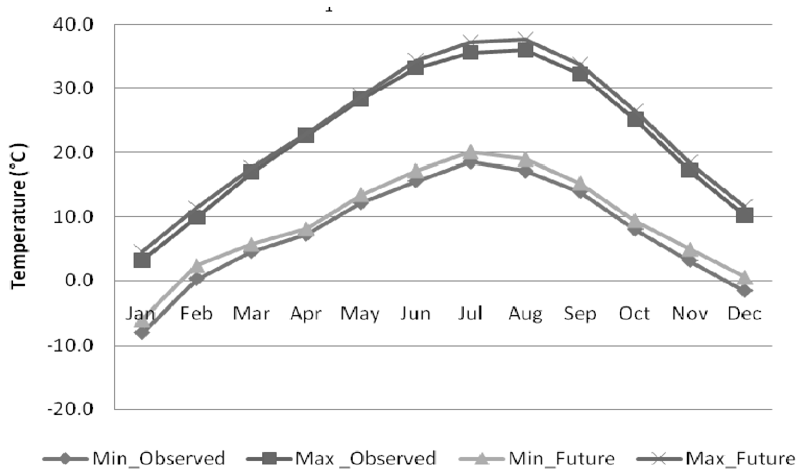

Fig. 6: Variation in mean minimum and maximum temperature of future and present period

Analyzing of tables 2 and 3 indicates that changes will occurs in all water balance components with the respect of present model data duration (2001 – 2010) in future under SRESin PRECIP, PET, SURQ, PERC, and WYLD and slight decrease in ET.

Table 3: Changes in Water Balance for future period with Comparison of Present Model Data

Time Series	PRECIP	PET	ET	PERC	SURQ	WYLD
Observed(2004 - 08)	525.4	1132.0	210.8	67.4	82.1	298.2
Ensemble mean (2001-2010)- Present	525.2	1128.9	272.4	59.4	55.5	243.1
Ensemble mean (2021-2050)-Future	554.2	1173.3	265.7	67.9	64.2	280.1
Change (Ensemble Future - Ensemble Present)	29.1	44.3	-6.8	8.6	8.7	37.1

Table 4 indicates the ensemble monthly change of water balance componants in Amu Darya River Basin with the repect of ensemble present model (2001–2010) A1B and A2 scenarios data and ensemble future model A1B and A2 scenarios (2021–2050). It shows different changes in different components in varioes months. Maximum increase changes in precipitation PRECIP are in october, March, January, and April months respectfully, while the Maximum decrease change will occure in Febuaray and May months. PET shows always increaseing mode and maximum values will occure in Auguest, July, and June months, while the minimum rates will occure in March and April. Changes in ET signify the variation in all months are mostly in decrease rates only in January, and March months are increasing and in september shows no change. PERC changes indicate that except month Feburary, the other months valus are will increase according periticted data, while during months of July–September will no change occur, and maximum change shows in January month.

Monthly SURQ chnges pattern is the same with PERC, but the maximum volume change is in March and October while the maximum changes value of PRECIP is also occure in that months.WYLD monlthy changes pattern is the same as PERC and SURQ, though the maximum change value occure in month of January and shows no change in month September. Figure 7 illustrate the average monthly change in precipitation and surface runoff of present data with respect the future (2021–2050) for ensemble mean of two scenarios.

Table 4: Monthly Average Future Change with Present Data of Water Balance Components in Amu Darya River Basin

Month	PRECIP	PET	ET	PERC	SURQ	WYLD
Jan	6.5	3.1	2.5	6.0	0.7	12.0
Feb	-3.3	2.1	-0.2	-4.7	-2.7	-3.6
Mar	7.5	0.8	-2.0	2.5	3.1	6.5
Apr	6.2	0.4	-2.1	1.6	2.1	5.6
May	-1.5	2.3	0.7	0.7	0.6	2.7
Jun	-0.2	6.1	-2.7	0.0	0.0	1.4
Jul	-0.6	7.3	-0.9	0.0	0.0	0.2
Aug	0.1	9.0	-0.3	0.0	0.0	0.2
Sep	0.0	6.1	0.0	0.0	0.0	0.0
Oct	9.7	4.0	-1.4	1.2	2.8	6.7
Nov	4.3	2.0	-0.7	0.9	2.0	4.2
Dec	0.3	1.2	0.4	0.3	0.1	1.3

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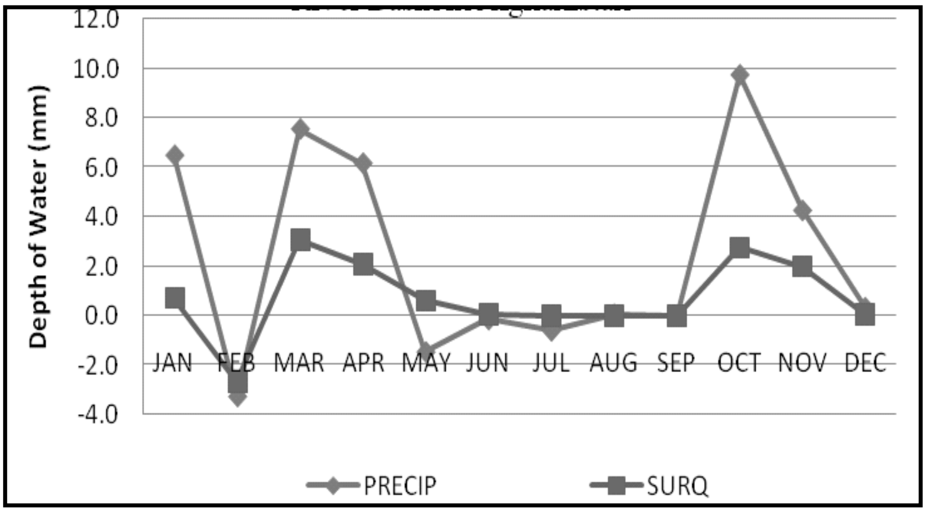

Figure 7 illustrate the average monthly change in precipitation and surface runoff of present data with respect the future (2021–2050) for ensemble.

4. Critical analysis and discussion

The science of assessment of vulnerability of hydrological system to climate change is not straight forward exercise because of confusing concerning about conceptualization of vulnerability among different scholarly communities. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2001, p.995). The operational definition of vulnerability studies are imprecise in nature and also lead to diversification methodological approaching for mapping it and some does not explain the functional relation between variables. In this case study the process of developing vulnerability framework has to be represented by interrelated components; hydrological modelling, climate projection modelling and assessment of socio-economic and environment impact assessment. The required realistic models are depend upon access and availability of reliable data on hydrology parameter, climatic variables and socio-economic indicators to develop scenario that are suitable for vulnerability and impact assessment. In unstable country like Afghanistan it is difficult to get all these information for regional climate change projections and simulation for vulnerability and impact assessment of water resources in Amu Darya River. The limitation of getting reliable data combined with uncertainty factor in understanding impact of climate change on local systems has raised concern about the ability to manage water resource by developing simulation models for climatic and hydrological changes at the local scale, and has compelled scientist to develop methods for understanding vulnerabilities, including how to downscale climate models. The World Bank, in collaboration with FAO and different formal institution of Afghanistan should intend in creation in above information for sustainable management of water resource of Amu Darya.

In this situation SWAT model has been applied in Amu Darya basin to assess the impact of climate change on water, sediment and agricultural chemical yields in large complex basins with varying soil types, land use and management conditions. In this model empirical and physically-based equations are combined by using readily available inputs, and enables resaerchers to study long-term impacts of climate variability on hydrological system at local scale. The above said river basin model has a limitation in application of this model in country like Afghanistan that has varying Physiographic and climatic characteristics with limited data availability. Mapping the impact of climate variability on hydrology and computing of vulnerability due to extreme events in unstable country depend upon projection of climate variables at global scale and downscaling global to local scale. Due to practical reason, no data are available in this country since 1980 and few works are done to understand the hydrological risk due to climate change. Hence the data used in the case study area observed data (2004 – 2008), developed present model (2001 – 2010) and computed future model (2021 – 2050) are simulated with SWAT model using A using A1B and A2, scenarios and compared. The limitation using this type methodology can be compared by taking examples of similar work in different part of world. The limitation in applying GCM model paradigms when down to catchment basin are uncertainty factor in prediction and also difficulty in associating the future socio-economic attribute in impact assessment studies (Ghosh & Mishra, 2010)**.** The variable which inaccurately predicted in a hydrological cycle from GCM to regional scale is precipitations (Ojha et al.). They have also proved that Artificial Neural Network (ANNs) performed much better than multiple regression technique. ANNs are recently used in hydrological modeling and water resources management studies and particularly used for modeling non-linear relationships where precise quantitative forms of such relationship are unknown or cannot be specified explicitly (Adeloye, 2009).

The other challenges while assessing the impact of climate change in these regions were demographic, factors, inadequate or non existence of water policies, inefficient management strategies and most important lack of adequate and reliable data. In view of the fact that this types studies related to simulation of vulnerability and impact assessments of resources are not well developed in this part of the world. The need of time is to take stock and exchange of experience of highland countries as well regional and international organization on climate change modelling methodologies, tools, model projections, downscaling techniques and knowledge gaps, as well as ways in which vulnerability can be assessed in view of better understanding the effects of climate change on sustainable development in Afghanistan and the whole of the Hindu-Kush Himalyan region.

5 Conclusions

The impact of global climate variability and change on hydrology and water resources needs to be quantified and modelled at river basin scales. The most credible tools of climate projections available are GCMs providing projections at much larger spatial scales. Yet downscaling of GCM projections of climate variability for impact assessment studies—which is very much what is needed on the ground—is hindered by uncertainty factors. The sources of the uncertainties are due to different GCM models (different parameters used for mapping climate systems) as well as uncertainties due to future socio-economic scenario. The latter has implications on carbon emissions and adapting with upcoming changes, and hence on the climate system, leading to scenario uncertainties.

Afghanistan has addition challenges in terms of attempting to use models for effectively mitigating and adapting to climate change. Weak institutions; lack of long-term, time series observations on the hydrologic cycle; and lack of resources to tap into the available data internationally all inhibit attempts at supporting on-the-ground adaptation with climate and water models. Any application of models must factor in these constraints.

The study reported here assessed and identified climate change impacts on sensitive hydrologic parameters by using a SWAT model in the Amu Darya River Basin, one of the important rivers in Afghanistan. Such assessments are not intended to be accurate predictions or even projections of future climate or hydrological conditions. They are examples of the direction and relative magnitude of changes in streamflow that could be associated with various conditions of specific (and potential) climate scenarios adopted. Future projections of A2 and A1B scenarios of bias-corrected CGCM3 GCM used in SWAT show that there is increase in the precipitation, maximum and minimum temperature. Results show that there is increase in PET, surface runoff, percolation, and water yield. There is slight decrease in evapotranspiration due to change in high intensity rainfall. These changes and prior information will considered in future development in the area.

How useful is such work for local adaptation? That might depend on how severe the study's limits are, as well as communication of the results to people who need them.

A main limitation of this study is the difficulty in capturing water allocation in the Amu Darya river. That is due to lack of knowledge of local water allocation practices and small scale patterns, as well as lack of clarity in actors that influence water distribution. The accuracy and quality of this model depend strongly on the quality of the input data and the information available to a water manager. That leads to an interesting feedback loop. Models are not so useful to local actors without locally specific applications. The models cannot be made locally specific without local input. The local actors do not have the small-scale data available. This cycle is difficult to break in a country such as Afghanistan that is starting to rebuild from decades of conflict and neglect while still embroiled in an internal violent conflict.

Nonetheless, should social conditions permit the collection, archiving, and application of reliable and accurate information feeding into the models from the ground up, while contributing from the top-down to local decisions, that will help to support addressing the water management challenges in the Amu Darya. Aspects of such methods, connecting the top-down with the bottom-up, might be transferable elsewhere around the Hindu-Kush Himalayan region. The priority steps are likely to be better management of land use especially with regards to cropping patterns; improved water management, especially regarding conservation of the scarce resources which could become scarcer under climate change; and flood warning systems. Naturally, that will need to involve people in communities more, something which the models applied here do not factor in.

But people often ask for information when changing the way they approach their day-to-day livelihoods. The top-down modelling work presented for the Amu Darya has the potential for applying directly to local adaptation, as long as some of the limitations are resolved. The modelling work presented here could be further refined by including more accurate and higher resolution data to climate change and hydrological models. Note that the key has been improved accuracy. To a large degree, the models are precise enough for local adaptation, but not accurate enough. Improving accuracy without changing precision would be a significant step forward for local adaptation.

The work presented here could also be further developed to an integrated, locally-relevant model by including information and inputs from water managers, water users, water-related policy makers, and water-related decision makers. That would be everyone from local politicians to dam operators to private engineers building dikes to farmers to villagers collecting their drinking water from a well. Again, a connection between those managing and using the water, and those sitting afar running the river models, would contribute towards the applicability of climate change and hydrological modelling to local adaptation. That would lead to more sustainable river basin planning and management decisions in Afghanistan, with possible implications for the rest of the HKH region.

To move this forward, specific recommendations are:

1. On the hazard side, a review would be useful of the methodologies and tools available for developing simulation models for climate change parameters and hydrological variables at all scales of the Amu Darya. That needs to take into consideration the knowledge gaps, data gaps, and technology gaps of Afghanistan and the challenges given the security situation there. For example, if top-end PCs are needed to manage data available or to run locally downscaled models, then how useful is it to have those data or models? If the models take several hours to process locally, or if a fast web connection facilities the analysis, how can that be managed in the context of an erratic power supply and unreliable internet? These questions need to be addressed directly.

2. On the vulnerability side, similar data and analysis limitations exist. There is an absence of comprehensive, locally relevant demographic, sociological, and political data. Similarly, different populations might have different water-related needs and concerns, but that information is unknown.

Much more work on the human, social, and community side is needed to match people's needs with what models can offer.

3. As part of linking 1 and 2, an small-scale assessment of the Amu Darya River through using local scale hydrological model driven by local scale projection of future climate change variables which go a long way towards making models relevant for local adaptation. That is pushing the limits of what is technically feasible at the moment, but it represents a cutting-edge, exciting research area with a potential to make a difference. Not just in any results, which are unknown, but in supporting people being more aware of their own environment making their own decisions—even the models, ultimately, are still not accurate enough for local decision-making.

4. All the above need to be managed in the context of Afghanistan's uncertain future and volatile security situation. Such an approach is almost unprecedented in science and development, but it would assist in learning how to support local adaptation in a protracted conflict zone.

5. The standard development mantra of effective capacity building, capacity development, and capacity maintenance hold true here. The above recommendations need outside support and direction, but cannot be implemented without local control. That requires a long-term commitment from everyone, outsiders and locals, to address capacity gaps and to catalyse efforts to move from information to action—and maintaining that over the long-term.

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