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Vulnerability assessment of water resources in Amu Darya river basin, Afghanistan

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ABSTRACT

The Amu Darya is the biggest river basin in Central Asia shared by Afghanistan, Tajikistan, Turkmenistan, and Uzbekistan. Vulnerability assessment of water resources in Amu Darya River Basin was estimated using the methodology developed by UNEP and Peking University, China. The Vulnerability Index of Amu Darya River Basin, falls in (0.53) value which indicate that the Amu Darya River Basin is under high stress of water resources. Ecological insecurity contributes most to the water resources vulnerability. In order to mitigate the stress, it is recommended to develop policy to mitigate the stress and develop long term strategic plan with focus on capacity building to manage the water resources.

Key words: Vulnerability index, river basin, water resources, stress.

1. Introduction

Afghanistan is located between latitudes 29.5N-38.5N and longitudes 60.5E-75E with total geographical area of 654,000 km^2. It is bordered by Tajikistan, Uzbekistan, and Turkmenistan to the north, Iran to the west, Pakistan to the south and east and China. Much of the country is dominated by the Hindu Kush, the westernmost extension of the Karakorum and the Himalayas. Over three-quarters of the land are mountainous. The great mountain ranges of Pamir and Hindu Kush divide the country with high area of planes in the north, a mountainous central area, mountains and foot hills in the east and south east and lowland to the south and west. It thus combines the sharp contrasts of high mountains with more protected valley. Figure 1 shows Afghanistan's rivers and watershed basins. The population is 26 million roughly; 23.3% urban, 71% sedentary in the rural areas and 5.7% nomads (Estimated Population of Afghanistan, 2010).

The surface water per capita in Afghanistan is estimated at 2,480 m^3/year. The present water withdrawal in the country is about 27 BCM per year, out of which 99% is allocated to the agriculture and only 1% is consumed in municipal and other uses (Faver and Kamal, 2004). Approximately 27% of Afghanistan lies above 2,500m elevation (Ahmad and Wasiq, 2004). The snow line is between 4000m - 5000m, so there is little permanent snow and there are few glaciers to the far northeast of Afghanistan. Outside the mountainous areas that dominated the center, much area of Afghanistan is lying in arid plain land. Deserts of different types occupy about 18 percent of Afghanistan. Only 17% of the country occupied by rivers valleys and water body, which include the valley of the Amu Darya, Northern, Helmand, Harrirud, and Kabul (Indus) River Basins as well as small rivers and other water resources (Faver and Kamal, 2004).

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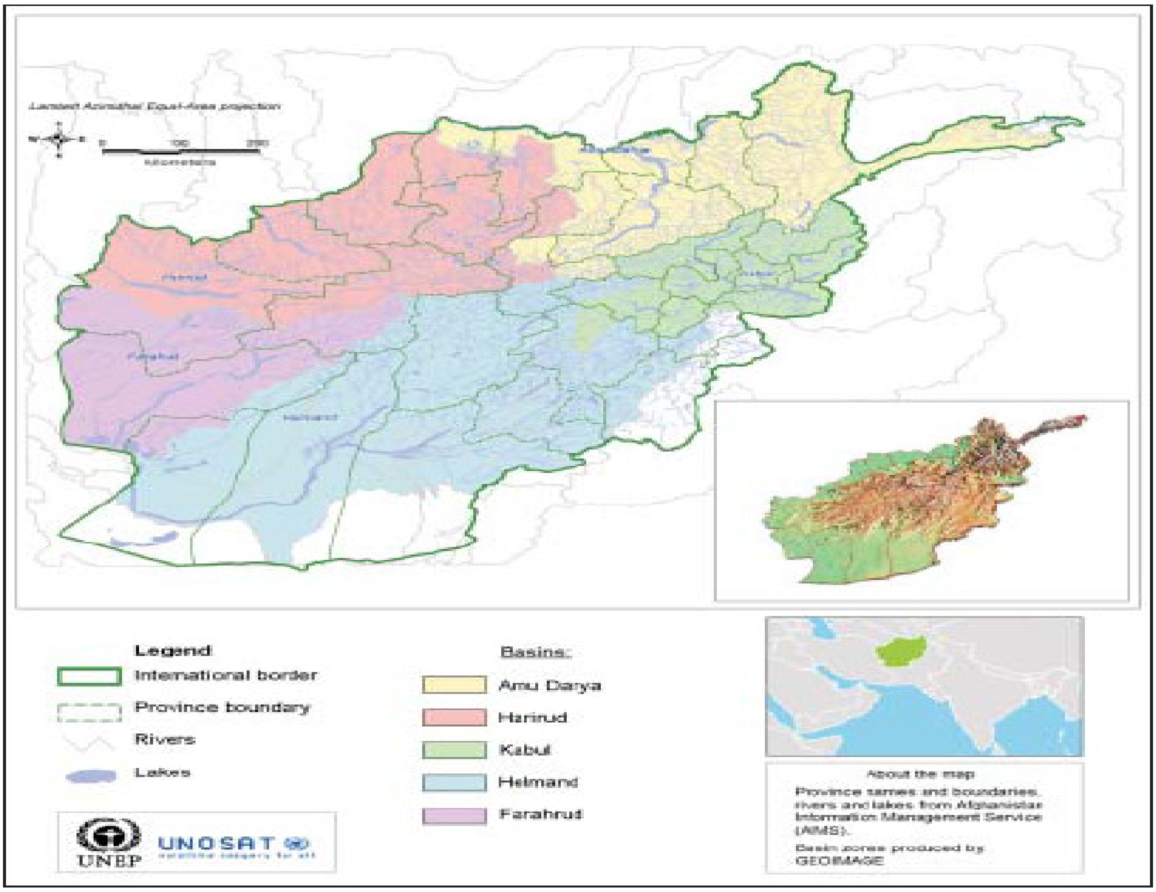

Figure 1: Afghanistan water basins and river (Source: UNEP, 2003)

The Amu Darya River Basin (ADRB) covers 14 percent of the Afghanistan national territory and more than half (57 percent) of the total annual water flow in the country, has its headwater in the High Pamir Mountains mainly in West Himalayas glaciers located in north west of Afghanistan. The highest point in Afghanistan is Mount Nowshak (or Nowshakh) at 7,484 m which is located in Amu Darya River Basin and the lowest point is about 313m in the Basin (UNEP, 2009).

The Amu Darya basin has its headwater in the High Pamir Mountains of Afghanistan and Tajikistan. The northern branch of the Amu Darya, the Ab-i Pamir River, has its source in Zor Kul Lake, which is shared between Tajikistan and Afghanistan. The southern branch, the Wakhan River, flows out of Chakmatin Lake. The Amu Darya River (the classical Oxus River) runs for 2,400 km 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. 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.

Therefore, the overall aim of this paper is to assess the vulnerability index on water resources of Amu Darya River Basin.

2. Methodology and methods

Vulnerability Index is calculated based on the methodological guidelines prepared by UNEP and Peking University (UNEP-PKU, 2008). In present study, the input data were obtained from the FAO, AIMS, ADB, WWDRII, NRCS, HWSD, the Center for Development Research, Germany.

2.1 Vulnerability index

Assessment of river basin vulnerability need proper understanding of four components of water resources system as follows:

1. Availability of water resources
2. Enhancement and usage of water resources
3. Ecological health of water resources base on supply and demand relationship, and
4. Management component of water resources

An advance analysis can pursue by accounting the Vulnerability Index (VI), based on following component of water vulnerability:

1. Resources Stresses (RS)
2. Development Pressures (DP)
3. Ecological Insecurity (ES), and
4. Management Challenges (MC)

Thus, the vulnerability index (VI) for the river basin can be expressed with this equation:

$$VI = f\ (RS, DP, ES, MC)$$

Where:

VI = Vulnerability Index

RS = Resource Stresses

DP = Development Pressures

ES = Ecological Insecurity

MC = Management Challenges

The value of vulnerability ranges from (0 to 1), where the (1.0) value signifying the most vulnerable situation in the region. The greater value of Vulnerability Index is actually address the more resource stresses, development pressures and ecological insecurity, but low management capacities.

To assess the Vulnerability Index, the indicators for each component should determine and quantify separately.

2.1.1 Resource stresses (RS)

The general situation of vulnerability of water resources can be expressed as “scarcity” and “variation” of the water resources. Water scarcity refers to the richness of the water resources base to meet the demands of the basin population. It is generally expressed as per capita water availability and compared with the generally-accepted minimum level of per capita water requirement proposed by Falkenmark and Widstrand (1992) (1,700 $m^3.person^{-1}.year^{-1}$). The variation in the water resources is expressed by the coefficient of variation (CV) of precipitation.

a) Water scarcity parameter

The scarcity of water resources can be expressed in terms of annual per capita water resources availability of a region or a basin, in comparison to the generally agreed minimum level of per capita water resources requirement (1,700 m^3/person). That is,

$$RS_s = 1700 - R / 1700 \qquad if\,(R \leq 1{,}700)$$

$$RS_s = 0 \qquad if\,(R > 1{,}700)$$

where:

RSS = water scarcity parameter; and

R = per capita water resources availability per year (m3.person-1.year-1).

b) Water variation parameter

The variation of water resources is expressed by the coefficient of variation (CV) of precipitation over the last 50years. A CV value equal to or greater than 0.30 is taken to indicate the most vulnerable situation and expressed as:

$$RS_v = CV/0.30 \qquad if\,(CV < 0.30)$$

$$RS_v = 1 \qquad if\,(CV \geq 0.30)$$

where:

RS_V = water variation parameter.

2.1.2 Development Pressures (DP)

Freshwater is recharged through a natural hydrological process. Over-exploitation of water resources disrupts the normal hydrological process, ultimately causing imbalance in supply and demand. The water resource development rate (i.e., percentage of available water supply, relative to the total water resources) is used to demonstrate the current level of pressures on the resources, whereas access to improved drinking water sources is used to assess the state of use to meet basic societal demand of freshwater.

a) Water exploitation parameter

This parameter is based on the water resources development rate (i.e., ratio of water supply and total water resources availability), and is used to represent river basin’s capacity for a healthy renewable process.

$$DP_e = WR_s/WR$$

Where:

DP_e = water exploitation parameter
WR_s = total water supply (capacity); and
WR = total water resources.

b) Safe drinking water inaccessibility parameter

This parameter summarizes the state of social use of freshwater (i.e., how freshwater resources development facilities address the fundamental livelihood needs of the population). It can be calculated with the following equation:

$$DP_d = P_d/P$$

Where:

DP_d = Safe drinking water inaccessibility parameter;

P_d = Population without access to improved drinking water sources; and

P = Total population.

2.1.3 Ecological Insecurity (ES)

The volume of wastewater discharged to rivers (representing the water pollution status) and vegetation cover (presenting the vulnerability of the natural landscape/ecosystem deterioration) are used for the purpose of assessing the ecological health of river basins. As a benchmark, it is assumed that when the volume of wastewater discharged exceeds 15 percent of the total water resources, the wastewater discharges merit concern because they make the water system vulnerable. The poor quality of surface water can lead to increasing groundwater extraction for agricultural and domestic consumption. The ecological health of a river basin was measured with two parameters; namely, the water quality/water pollution parameter and ecosystem deterioration parameter.

a) Water pollution parameter

The contribution of water pollution to water resources vulnerability is represented as the ratio of total untreated wastewater and the total water resources. The ratio equal to or greater than 15 percent of the available water is considered to represent the most vulnerable situation. Thus, the water pollution parameter (EH_p) is expressed as:

$$\mathrm{EHp} = \frac{WW/WR}{0.15} \qquad if(WW < 0.15 * WR)$$
$$\mathrm{EHp} = 1 \qquad if(WW \geq 0.15 * WR)$$

Where:

EH_p = water pollution parameter
WW = total wastewater volume (m^3); and
WR = total water resources (m^3)

b) Ecosystem deterioration parameter

This parameter is represented by the ratio of the basin area without vegetation cover to the total basin area. The area under forest and wetlands is considered as the vegetation coverage:

$$EH_e = A_d/A$$

Where:

EH_e = Ecosystem deterioration parameter
A_d = Basin area without vegetation (forest area and wetlands) coverage (km^2); and
A = Total basin area (km^2).

2.1.4 Management Challenges (MC)

In addition to the availability (and uncertainty) of water resources, management efficiency (or inefficiency) also contributes to the vulnerability of the basin freshwater resources. Management challenges are measured with the following three parameters:

a) Improved sanitation inaccessibility parameter

The computation of this parameter is based on proportion of the population in the basin that lacks access to improved sanitation facilities, as follows:

$$MC_s = P_s/P$$

Where:

MC_s = improved sanitation inaccessibility parameter
P_s = population without access to improved sanitation; and
P = total population

b) Conflict management capacity parameter

The conflict management capacity parameter parameter (MC_c) is determined by expert's consultation and scoring criteria developed by UNEP (2008) as given in Table .

Table 1: Conflict management capacity parameter assessment matrix (Source: UNEP, 2008)

Category of inability	Description	Score and Criteria		
		0.0	0.125	0.25
Institutional inability	Transboundary institutional arrangement for coordinated water resource management	Strong institutional arrangement	Loose institutional arrangement	No institution existing
Agreement inability	Written/signed policy/agreement for water resource management	Concrete/detailed agreement	General agreement only	No agreement
Communication inability	Routine communication mechanism for water resource management	Communications at policy and Operational levels	Communication only at policy level or operational level	No communication mechanism
Implementation inability	Water resource management cooperation actions	Effective implementation of river basin-wide projects/programs	With joint project/program, but poor management	No joint project/program

2.1.5 Vulnerability Index

Based on weights are assigned to each component of the vulnerability index to calculate the index using the following equation:

$$VI = \sum_{i=1}^{n}\left(\left(\sum_{j=1}^{mi}[Xij \times Wij]\right) \times Wi\right)$$

Where:

VI = vulnerability index
n = number of vulnerability components
mi = number of parameters in ith component
xij = value of the jth parameter in ith component
wij = weight given to the jth parameter in ith component; and
Wi = weight given to the ith component

To give the final VI value in a range from 0 to 1.0, the following rules were applied in assigning the weights:

- The total of weights given to each indicator should equal 1.0; and
- The total of weights given to all components should equal 1.0.

Different vulnerability classes and their interpretation are mentioned in Table 2. Depending on the value of overall VI, it is easily of see the status of basin (UNEP, 2008).

Table 2: Interpretation of vulnerability Index - Source: UNEP, 2008

Vulnerability Index	Interpretation
Low (0.0 - 0.2)	Indicates a healthy basin in terms of resource richness, development practice, ecological state and management capacity. No serious policy change is needed. However, it is still possible that in the basin, moderate problems exist in one or two aspects of the assessed components, and policy adjustment should be taken into account after examining the VI structure.
Moderate (0.2 –0.4)	Indicates that the river basin is generally in a good condition toward realization of sustainable water resource management. However, it may still face high challenges in either technical support or management capacity building. Therefore, policy design of the basin should focus on the main challenges identified after examination of the VI structure, and strong policy interventions should be designed to overcome key constraints of the river basin.
High (0.4 – 0.7)	The river basin is under high stress, and great efforts should be made to design policy to provide technical support and policy back-up in order to mitigate the stress. A longer term strategic development plan should be made accordingly with focus on rebuilding up of management capacity to deal with the main threat.

Severe (0.7 – 1.0)	The river basin is highly degraded in water resource system with poor management set up. Management for the restoration of the river basin's water resource will need high commitment from both government and general public. It will be a long process for the restoration, and an integrated plan should be made at basin level with involvement from agencies in the international, national and local level.

3. Results and discussion

3.1 Resource stresses

Analysis revealed that in the Amu Darya River Basin annual per capita water availability is more than three of the minimum requirement of 1,700 $m^3.capita^{-1}.year^{-1}$(Table 3). Thus, there is null water scarcity. In the same time the annual water variation parameter (RS_v) is highest. There is sufficient water, suggesting a spatial variability of water resources. The Amu Darya River Basin, with a catchment area of 90,692 km^2, and inhabitated by nearly 2.6 million people, is shared by Afghanistan, Tajekistanand Uzbakistan. Snowmelt and spring precipitation in the mountainous upper regions of the west hemalya are the main runoff sources.

Table 3: Water resources stresses in Amu Darya river basin

Indicators		Parameters	
Available water resources (m^3/capita)	Coefficient of variation in precipitation	RS_s	RS_v
6,168	0.40	0.00	1.00

3.2 Development pressures

Freshwater is recharged through a natural hydrological process. Over-exploitation of water resources disrupts the normal hydrological process, ultimately causing imbalance in supply and demand. The water resource development rate (i.e., percentage of available water supply, relative to the total water resources) is used to demonstrate the current level of pressures on the resources, whereas access to improved drinking water sources is used to assess the state of use to meet basic societal demand of freshwater. The water resources development pressures (DPe) is estimated in Amu Darya River Basin 17 per cent, indicate the annule per capita water withrawal is 6168 $m^3.capita^{-1}$. Assessment indicates that more than 90 percent of the water being withdrawn is used in the agriculture sector. The concern is, luck of water infrastructure to provide safe drinking water to the population. Less than one forth of basin population have access to water from improved water sources (Table 4).

Table 4: Water Development Pressures in Amu Darya Rover Basin

Indicators			Parameters	
Total water use (BCM/year)	Water Basin resources (BCM/year)	AISDW (% Population)	DP_e	DP_d
6	35	13	0.17	0.54

AISDW = Access to Improved Sources of Drinking Water

3.3 Ecological insecurity

The vegetation cover especialy forest and rangeland in the Amu Darys Basin has been reduced, due to continuous demands for fuel wood and illegal logging. A continuous decline in the wetland vegetation cover has been observed since 1985. The water quality is generally good in the upper and silityly in lower basin (Table 5).

Table 5: Ecological Health of Amu Darya River Basin

Indicators			Parameters	
Wastewater Volume (BCM/year)	Water Resources (BCM/year)	Vegetation Cover (% area)	EH_p	EH_e
5.25	35	68.5	1.00	0.32

3.4 Management challenges

Water resources management in the Amu Darya river Basin focuses primarily on management of irrigation water. Very few skilled professionals to undertake development programs and lack of coordination among relevant organization. The combined effect of these factors has resulted in management stresses in the Basin (Table 6).

Table 6: Management capacity of Amu river Basin

Indicators			Parameters	
Water Use (BCM)	Population (in million)	AISF (% of population)	MC_s	MC_c
6	2.6	43	0.57	0.60

AISF = Access to Improved Sanitation Facility

3.5 Vulnerability index

The vulnerability index is calculated giving equal weight to four components of vulnerability index (Table 7). The vulnerability indices suggest that water resource systems in the Amu Darya River Bsin is highly vulnerable according to criterio suggested by UNEP (Table 2). The Amu DaryaRiver Basin is more vulnerable (VI = 0.53). Ecological insecurity contributes most to the water resources vulnerability, while management challenges pose the greatest risk in the the Basin. Fother more the management challenges in the Amu Dary River Basin is also high. With assessment of (0.53) VI the Amu River Basin is under high stress. There is need of great efforts to propose policy to provide technical support and policy back-up in order to mitigate the stress.

Table 7: Summary of Vulnerability Parameters of Amu Darya River Basin

RS	DP	ES	MC	VI
0.50	0.36	0.66	0.39	0.53

3.6 Climate change and water resources

SWAT model has been applied in Amu Darya basin to assess the impact of climate change on water (Waheed, 2011; Mohanty et al., 2012). In this model, physically-based equations are used with readily available inputs i.e., soil types, landuse classes, climatic data. There is limitation in application of this model in country like Afghanistan that has varying Physiographic and climatic characteristics with limited data availability. Data used in the case study area observed data (2004 – 2008), GCM simulated present condition (2001 – 2010) and GCM simulated future data (2021 – 2050). 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.

4. Conclusions

In this case study the process of developing vulnerability framework has to be represented by interrelated components. 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. Vulnerability assessment of water resources in Amu Darya River Basin was estimated using the methodology developed by UNEP and Peking University, China. The Vulnerability Index of Amu Darya River Basin, falls in (0.53) value which indicate that the Amu Darya River Basin is under high stress of water resources. Ecological insecurity contributes most to the water resources vulnerability. In order to mitigate the stress, it is recommended to develop policy to mitigate the stress and develop long term strategic plan with focus on capacity building to manage the water resources.

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