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# Mapping Vulnerability to Climate Change

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## Abstract

This paper develops a methodology for regional disaggregated estimation and mapping of the areas that are ex-ante the most vulnerable to the impacts of climate change and variability and applies it to Tajikistan, a mountainous country highly vulnerable to the impacts of climate change. The authors construct the vulnerability index as a function of exposure to climate variability and natural disasters, sensitivity to the impacts of that exposure, and capacity to adapt to ongoing and future climatic changes. This index can inform decisions about adaptation responses that might benefit from an assessment of how and why vulnerability to climate change varies regionally and it may therefore prove a useful tool for policy analysts interested in how to ensure pro-poor adaptation in developing countries.

Index results for Tajikistan suggest that vulnerability varies according to socio-economic and institutional development in ways that do not follow directly from exposure or elevation: geography is not destiny. The results indicate that urban areas are by far the least vulnerable, while the eastern Region of Republican Subordination mountain zone is the most vulnerable. Prime agricultural valleys are also relatively more vulnerable, implying that adaptation planners do not necessarily face a trade-off between defending vulnerable areas and defending economically important areas. These results lend support to at least some elements of current adaptation practice.

# Mapping vulnerability to climate change

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## 1. Introduction

It is well-understood that poor people in the poorest countries are the most vulnerable to the impacts of anthropogenic climate change (World Development Report, 2009; Stern, 2006). The poor are adversely impacted by climate change because they live in heavily impacted countries and locations within those countries; depend on natural resource-based livelihoods that are disproportionately affected by climate change; and have the weakest ability to adapt to the impacts. Yet while there have been important conceptual advances in the understanding of vulnerability and adaptation, quantitative estimates of how vulnerability varies across countries, regions, and sectors are only starting to emerge.

This paper develops a methodology for regional disaggregated estimation and mapping of the areas that are ex-ante the most vulnerable to the impacts of climate change and applies it to Tajikistan, a mountainous country highly vulnerable to the impacts of climate change. A geographically disaggregated picture of vulnerability to climate change is helpful for planning adaptation strategies in the same manner that a poverty map is helpful for designing anti-poverty policies and programs (Hentschel, Lanjouw, Lanjouw, and Poggi; 2000). The methodology presented here may prove a useful tool for policy analysts interested in how to ensure pro-poor adaptation in developing countries.

Adaptation matters: when category 3 cyclone Bhola hit East Pakistan (present day Bangladesh) in 1970, upwards of 500,000 people died. When in 1991 a category 4 cyclone hit Bangladesh, mortality was 138,000. In November 2007, cyclone Sidr, also of category 4, resulted in only 5-10,000 deaths. Bangladesh achieved this remarkable reduction in disaster mortality through a combination of early warning systems and cyclone shelters. Early warning systems spanned both high tech information systems and low tech outreach such as volunteers on bikes that spread warning messages. What this example shows is that the effectiveness of societies' adaptive capacity is paramount for how climate events translate into human and economic consequences (Heltberg, Siegel, Jorgensen, 2009). Another stark example is the impact of earthquakes in Haiti and Chile. While more than 200,000 people died in Haiti's 7.0 earthquake in January, 2010 from collapsed buildings, an 8.0 earthquake in Chile in February 2010 resulted in 486 deaths, many from tsunami waves. There is a saying among engineers that buildings, not earthquakes, kill people. Likewise, adaptation and maladaptation determine vulnerability to climate change and that is why adaptation planning needs to consider social dimensions and concede a greater role for social protection mechanisms (Heltberg, 2007; Heltberg, Siegel and Jorgensen, 2010).

We present what is, to our knowledge, the first regionally disaggregated map of climate vulnerability with national coverage in the literature. Our vulnerability index is also innovative in that it takes adaptive capacity explicitly into account. The vulnerability index we estimate addresses the question: if policy makers wish to direct funding toward the areas with the highest vulnerability to climate change, where should that funding go? And what are the factors that render some areas more vulnerable than

others? We do not estimate the cost and benefits of investing in different geographic areas and we therefore refrain from offering any policy prescriptions. Instead, the estimates presented here should be seen as a useful starting point for a dialogue about where the most vulnerable people are located and what factors render them more vulnerable than others. These are also the uses of a poverty map.

We adopt a theory-driven approach to constructing the vulnerability index based on the notion that vulnerability is a function of exposure to climate change and variability; sensitivity to the impacts of that exposure; and ability to adapt to ongoing and future changes (Hahn, Riederer, and Foster, 2009). Indicators and indices are useful for describing a complex reality in simple terms and permitting comparisons across space and time provided that they can be comprehended intuitively, are impartial, and are geographically comparable (Vincent, 2004). We agree with those authors that have argued that the 'adaptation deficit'—excessive vulnerability to current climate variability—is a good proxy of future vulnerability to climate change (e.g., World Bank 2009b). This motivates our focus on vulnerability to current climate variability, not projected future changes.

We illustrate our approach to climate vulnerability mapping with the case of Tajikistan which has been identified as the country most vulnerable to the impacts of climate change in the Eastern Europe and Central Asia region (World Bank, 2009a). Plans are under way to scale up adaptation efforts in Tajikistan under the Pilot Program for Climate Resilience and other. To inform these efforts, this paper seeks to assess how vulnerability to climate change and climate variability vary across regions of the country.

Tajikistan is a low income country and the poorest country in the ECA region. Much of the population and the economy of Tajikistan are in the two major valleys which are the loci of irrigated agriculture and where water availability is a major climate change-related concern. The remainder inhabits the mountainous areas of varying elevation where mudslides and other natural disasters are major risks. Adaptation strategies need to determine where to invest in planned adaptation. Such strategies face an apparent dilemma between protecting the core agricultural economy by investing in the most productive areas or to invest in disaster risk management in more remote mountainous zones.

Our assessment of vulnerability considers a range of factors beyond the geo-physical impacts of climate change and draws on diverse data sources including household surveys and weather station records. These factors include the extent to which assets and livelihoods are sensitive to impacts of climate change as well as the social, economic, and institutional factors that are likely to shape adaptive capacity. In Tajikistan, migration and elevation are two critical factors to consider. A common household livelihood strategy is overseas migration for work, mostly to Russia. Tajikistan received remittances equivalent to 40% of its GDP in 2008, almost all from male migration to Russia. Households in the rural highlands have on average almost 50%

more migrant workers than households in the rural lowlands, and correspondingly receive higher amounts of remittances.

The results suggest that vulnerability to climate change and variability varies substantially across regions and agro-ecological zones in ways that are not a priori obvious. The vulnerability index varies according to socio-economic and institutional development while exposure and elevation exert smaller influences: geography is not destiny. Like all indeces, these results are of course a function of assumptions made when constructing the index but they are far from trivial, as geographic and meteorological data carry considerable weight in the index formula. The results indicate that urban areas are by far the least vulnerable while the eastern Region of Republican Subordination (RRS) mountain zone is the most vulnerable. The results also suggest that Tajikistan's most remote and sparsely populated high-altitude mountains have medium vulnerability while prime agricultural valleys are among the more vulnerable areas. This implies that relatively vulnerable geographic areas can overlap centers of population and economic activity. Adaptation planners therefore do not necessarily face a trade-off between defending the most vulnerable areas and defending the economically most important areas from the impacts of climate change.

After this introduction, the paper is organized as follows. Section 2 discusses vulnerability and adaptive capacity. Section 3 introduces the data and methodology used for constructing the index. Section 4 presents the results and Section 5 offers concluding remarks.

## 2. Vulnerability and adaptive capacity

We define vulnerability as the risk of experiencing poverty or some other deprivation during some time interval, consistent with the social constructivist framework for understanding vulnerability (Füssel and Klein, 2006) and the Social Risk Management framework (Holzmann and Jorgensen, 2000; Heltberg, Siegel, and Jorgensen, 2009). Estimates of vulnerability to poverty normally focus on the risk of the household falling below the poverty line as a result of changes in income resulting from risky events. An individual or household is vulnerable to risk(s) associated with climate change if these risk(s) will result in a loss of well-being that pushes the individual or household below a threshold level of well-being. Vulnerability is a function of the risks, exposure and sensitivity to risks, and adaptive capacity. We define *exposure* to mean the chance that assets and livelihoods will be impacted by climate change risk and *sensitivity* as the susceptibility of assets and livelihoods exposed to risk.

Adaptive actions are adjustments in assets, livelihoods, behaviors, technologies, or policies that address ongoing and future climate changes (IPCC, 2007; Stern, 2006; UNDP, 2007; Smit and Wandel, 2006). Adaptation confers private benefits--it is in people's self-interest to adapt in order to safeguard lives and livelihoods. Adaptive actions comprise both private, club, and public goods. Heltberg, Siegel, and Jorgensen

(2009) define *adaptive capacity* as the ability to deploy social risk management strategies for reduction of risk and human vulnerability associated with climate change.

Even though resilience and adaptive capacity have been the subject of increasing research in recent years (Adger, 2006; Smit and Wandel, 2006) it is not well understood how it varies across countries, regions of countries, and sectors and how it can best be strengthened. The drivers of adaptive capacity include physical, financial, human, and social capital. Adaptive capacity is unequally distributed: it varies systematically along existing fault lines for inequality and social exclusion such as gender, ethnicity, and socio-economic status (e.g., Ribot, 2010). Therefore, the poor are not only the most exposed to the impacts of climate change, they are also the least equipped to adapt to it. Adger et al (2009) argue that the constraints to adaptation often are rooted in belief systems and social structures. For example, all cultures have different traditions for how, and what sources of climate knowledge, they use--traditions that are vitally important for how weather forecasts are used or whether early disaster warnings are heeded. The roots of maladaptation can thus be cognitive just as much as they can be rooted in financial constraints or flawed engineering. However, much remains to be learned about how these insights might translate into better adaptation interventions on the ground in different contexts.

## 3. Data and methodology

This section describes how the concepts of exposure, sensitivity, adaptive capacity, and vulnerability were translated into numerical indices; what variables were used; how variables were aggregated into sub-indices and sub-indices into a composite vulnerability index; and how sub-national geographical areas were determined.

**Conceptual approach**

Our measure of vulnerability to climate change takes as its starting point the IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2001) and incorporates social, economic, and natural science indicators. We construct the index of vulnerability as the simple average of three sub-indices: exposure, sensitivity, and adaptive capacity. In line with previous literature (e.g., Polsky et al., 2007), we include a range of climatic, economic, social, and institutional variables as the drivers of vulnerability and focus on vulnerability to current climate variability. One advantage of this approach is the reduction in dependence on climate models and projections which despite recent advances are still presented at too coarse a scale with too high degrees of uncertainty to be useful for regional analysis (Hahn, Riederer and Foster 2009).

We improve upon the approaches used by previous studies by covering all areas of the country, both rural and urban, and by carefully exploiting a host of available survey, census, and meteorological data. We use indicators of past climate variability to assess

exposure to natural disasters and climate variability; social, economic, and institutional characteristics of households and regions that affect their adaptive capacity; and health, livelihood, food security, and demographic characteristics that determine sensitivity to climate change impacts.

**From concept to choice of variables**

A number of judgments have to be made when translating the concepts into estimates of vulnerability at the sub-national level; this is particularly so for adaptive capacity. For example, does migration and urbanization reduce or increase vulnerability? Vincent (2004) interprets growing urbanization as a sign of weak rural resilience and therefore high vulnerability. However, in the Tajik context, migration is accompanied by remittances vital to the livelihoods of the household members left behind. At least to the migrant households, remittances help reduce vulnerability. We therefore treat remittances as adding to income diversification and improving adaptive capacity. We construct a variable measuring the extent of diversification of non-agricultural income sources at the household level which we believe to be a good indicator of how well communities have already adapted: well- diversified communities (including those with remittance incomes from migrants) are displaying adaptive behaviors and might be expected to continue to do so in the future.

A well-educated population with reasonable and diversified income sources and developed institutional structures is better able to manage risks and prevent biophysical impacts from translating into human impacts. We therefore also include in the adaptive capacity sub-index average per capita household consumption and the share of population with education above secondary.[1] Institutional strength and stability are also important for determining the coping range of a population. Governance and political stability are important criteria here but, unfortunately, no direct indicator is available at the sub-national level. However, three good proxies for institutional strength are available in our data and all contribute to adaptive capacity:

- Social capital and trust is measured in the form of generalized trust. The question "Generally speaking, would you say that most people can be trusted, or that you can't be too careful in dealing with people?" has been used in many settings to assess general interpersonal trust as a dimension of social capital. It is available for Tajikistan from the Life in Transition (LiTS) survey. We use the

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[1] Access to information and communications infrastructure is also arguably important in influencing vulnerability (Blake et al, 1994). In the past, authors have used telephone access measures as proxies for information sharing, early warning, and general connectivity. However, now that most households have cell phones, the value of telephone access as a proxy variable has arguably diminished. This leaves us with no usable data source on access to information.

proportion of households that state they have some or complete trust in other people.

- Quality of public services such as police, courts, education, health, and social assistance contribute toward adaptive capacity. Areas with good services will find it easier to respond to climate risks and to craft the public-private collaboration required to prepare for climate change. We measure this variable using LiTS data on the average number of public services (out of 8 max) for which households declare that they are either satisfied or very satisfied. If all households in a region were satisfied with the quality of all 8 public service areas, the value becomes 8. If no household is satisfied with any of the services, the value becomes zero.

- Corruption in daily interactions measures a key hindrance for adaptive capacity and, vice versa, absence of corruption makes adaptation easier and proxies institutional strength. We measure corruption using LiTS data on the average number of public services (out of 8 max) for which households declare that they never or seldom find it necessary to pay bribes in order to obtain the service in question (the services are the same as above, namely police, courts, education, health, and social assistance services).

Compared to adaptive capacity, constructing indices of exposure and sensitivity proved relatively straightforward. We construct the exposure index from variables measuring temperature and precipitation variability and natural disaster frequency. We construct the sensitivity index from variables measuring agricultural, demographic, health, poverty, and disaster-related sensitivity to climate variability. This is described in the following section.

**Variables in the index**

The exposure sub-index is comprised of the following six variables measuring exposure to variability and extreme values of temperature and precipitation as well as to natural disasters: (i) Standard deviation of the average monthly temperature 1950-90 (see formulas in Appendix 1); (ii) the range between maximum and minimum average monthly temperature; (iii) the frequency of extremely hot or cold months, defined as the frequency of months in which the average temperature exceeded 30 C or fell below - 10 C; (iv) the frequency of extremely dry months in the spring (less than 5 ml total precipitation per month) and summer (0 ml total precipitation per month); (v) the standard deviation of monthly total precipitation; and (vi) the frequency of weather related disasters between 1998-2009.

The sensitivity sub-index is comprised of five variables measuring agricultural, demographic, health, poverty, and disaster-related sensitivity to climate change and variability. Sensitivity of agriculture to impacts of climate change and variability is measured as the average of three variables: Area of irrigated land per capita, the degree of diversification of crop land-use measured by the Herfindahl index, and the share of

households whose main income source is agriculture. Demographic sensitivity is measured by the share of the population below 5 and above 65 years of age. Sensitivity to adverse impacts on health is measured by the average of two variables, the under-five mortality rate and the share of households relying on an unprotected water source. Sensitivity to poverty and hunger is measured by the share of households that report food insecurity (we avoid using the consumption-based measure of poverty because it correlates closely with income which is used in the adaptive capacity sub-index). Finally, sensitivity to the impacts of natural climatic disasters (as opposed to exposure to them) is measured by the mortality rate from natural climatic disasters and the estimated per capita economic costs of these disasters.

The adaptive capacity sub-index is comprised of four variables measuring consumption, education, income diversification, and institutional development: (i) household consumption per capita; (ii) share of population with education above secondary; (iii) the Herfindahl index of income diversification (higher value, more diversification); (iv) as already mentioned, institutional development and social capital is measured by the average of three variables: trust (share of households with general trust in other people); absence of corruption (share of households that never or only raring have to pay bribes); and political involvement (share of households that participated in presidential elections).

**Index methodology**
Various methods exist for aggregating variables into sub-indices and sub-indices into composite indices. Simple averages assume all variables carry equal weight. Weighted averages can be used to depart from the assumption of equal weights but introduce the need for 'expert judgment' to determine the weights, thereby introducing another element of arbitrary choice. Regression-based weights are only feasible when an objective measure of the outcome (in this case vulnerability) exists; this is not the case here since then there wouldn't be the need to compute the index. Eakin and Bojorquez-Tapia (2008) note that equal weighting makes an implicit judgment about the degree of influence of each indicator and propose a complex fuzzy logic-based weighting method as a more objective approach.

We elect to use simple unweighted averages as the simplest and least arbitrary method available. We use simple unweighted averages of normalized variables to form sub-indices and simple averages of sub-indices to form the overall vulnerability index. We include only variables that each represent distinct aspects of vulnerability and thereby avoid having the implicitly unequal weights that would result if two or more similar variables were included. We define variables in the most intuitive manner so that for the exposure and sensitivity sub-indices, the highest value always corresponds to the greatest vulnerability while for adaptive capacity, the highest value corresponds to the lowest vulnerability. We normalize all variables by a linear transformation into the 0-1 interval. In particular, variable x is transformed to x', where x' = (x -min x)/(max x -min x) where minimum and maximum is taken over the value of x across the regions.

We therefore calculate vulnerability as: Vulnerability = 1/3(Exposure + Sensitivity + (1-Adaptive Capacity)).

**Agro-ecological zones used in the analysis**
Tajikistan is characterized by highly variable geography, terrain, ethnic composition, and socio-economic status. Parts of the country are remote and sparsely populated highlands; other parts are fertile valleys of good agricultural potential. Some parts still feel the effect of the civil war in the 1990s. When exploring regional variability of Tajikistan in respect to climate change, selection of the level of analysis is dictated by a trade-off between overlooking important local difference and data availability constraints. We present our results at two levels of geographic aggregation, namely (a) for 10 agro-ecological zones and one composite urban area; and (b) for the rural areas of the oblasts, the four major administrative divisions of the country.

For the agro-ecological zone analysis, we divide Tajikistan into 10 geographical zones. The basis for this is a map of 14 agro-ecological zones developed by the World Food Program in a study on food security (WFP, 2007). These 14 zones were identified on the basis of homogeneous land cover and land use and based on consultation with local experts. We modify the WFP map by merging some of the agro-ecological zones so that they are continuous and homogeneous in altitude and terrain and so that sufficient data points are available for each zone. We limit ourselves to rural areas within these zones. Figure 1 shows the resulting zones which are further described in Appendix 2.



**Figure 1: The 10 agro-ecological zones with oblast capitals**
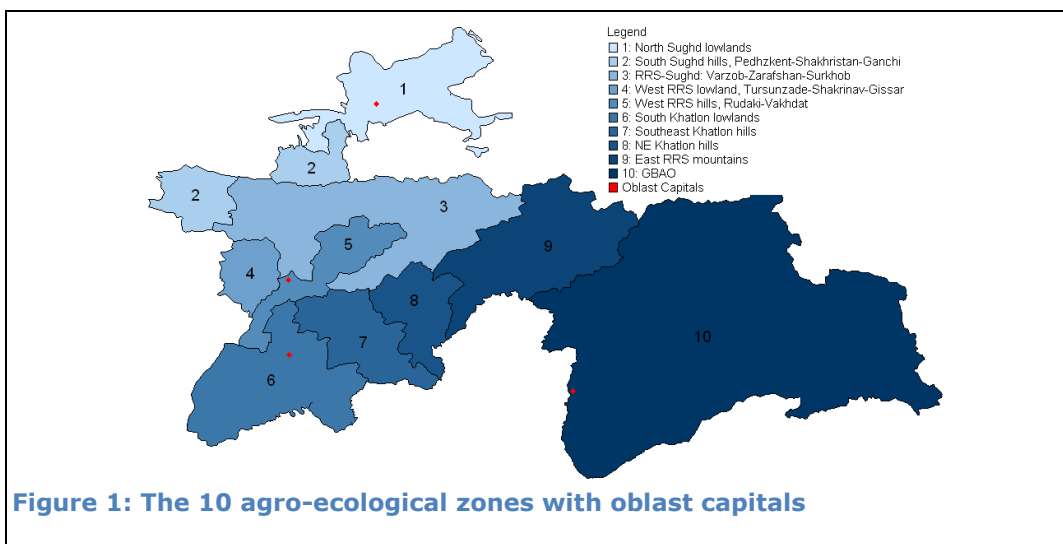
We also attempt to estimate urban vulnerability. The processes that drive vulnerability are often different in urban and rural areas, and adaptive responses are organized in distinct ways. Still, comparing urban and rural vulnerability is interesting and most of the data sources used in the analysis presented above are in fact available for the country's

major urban areas, namely Dushanbe (the capital), Khujand, Istaravshan, Kurganteppa, Kulyab, and Horog. Because of few observations in the household surveys for individual urban areas we group all urban areas into one. We estimate composite urban vulnerability using the same methods and data as for rural areas with the exception that for urban areas the agricultural variables are not included in the calculation of the sensitivity index.[2]

## 4. Results

The results show that vulnerability varies according to socio-economic and institutional development in ways that do not follow directly from exposure, geography, or elevation. Urban areas are by far the least vulnerable while the eastern RRS mountain zone is the most vulnerable and the remote GBAO mountains rank in the middle. In the following we first present results for rural agro-ecological zones, then for the urban areas, and finally for oblasts.

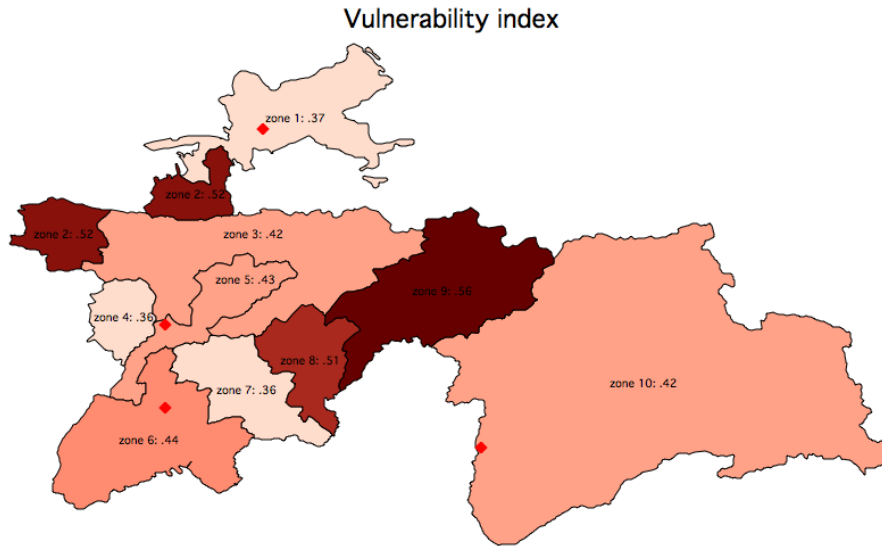### Results for agro-ecological zones

The results show substantial and sometimes surprising variation in vulnerability and its components. Overall vulnerability varies much less than exposure, sensitivity, and adaptive capacity; this is because the sub-indices tend to cancel each other out. For example, while the remote GBAO highlands experience the highest exposure, it also benefits from the highest adaptive capacity of any area combined with medium sensitivity. Overall, GBAO therefore has medium vulnerability according to these estimates. The lesson is that a full understanding of the determinants of vulnerability alters the results from what analysis of exposure to the impacts of climate change alone would have led to; such analysis would have placed GBAO in the top as the most exposed region.

The most vulnerable areas are the eastern RRS (Region of Republican Subordination) mountains, Southern Sughd hills, and Khatlon hills and lowlands (Figure 2 and Figure 3). These are areas of varying elevation and population density. The combined population of the three most vulnerable zones exceeds 500,000 (9% of the total) while that of the four most vulnerable zones—that is, including Khatlon lowlands' population of more than 1 million—exceeds 1.6 million (27% of the country's total). Although the zones are vulnerable for somewhat different reasons, they share a high degree of sensitivity to climate change, particular food insecurity, disaster sensitivity, and reliance on

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[2]Measures of crop diversification and irrigation per capita are only meaningful in the rural context. We use these variables to compare the rural areas within themselves, but they are not defined in the absence of agricultural land. Not using these values in calculating the index value for urban areas is algebraically equivalent to using the country average values of these variables.

agriculture. They also have weak adaptive capacity, in part stemming from low levels of income and education. Their exposure is only moderate but their high sensitivity and fairly moderate adaptive capacity render these areas vulnerable to climate change. Again, a full understanding of vulnerability leads to results that differ from what a focus on exposure would have indicated.



**Figure 2: Vulnerability map for Tajikistan (10 agro-ecological zones)**
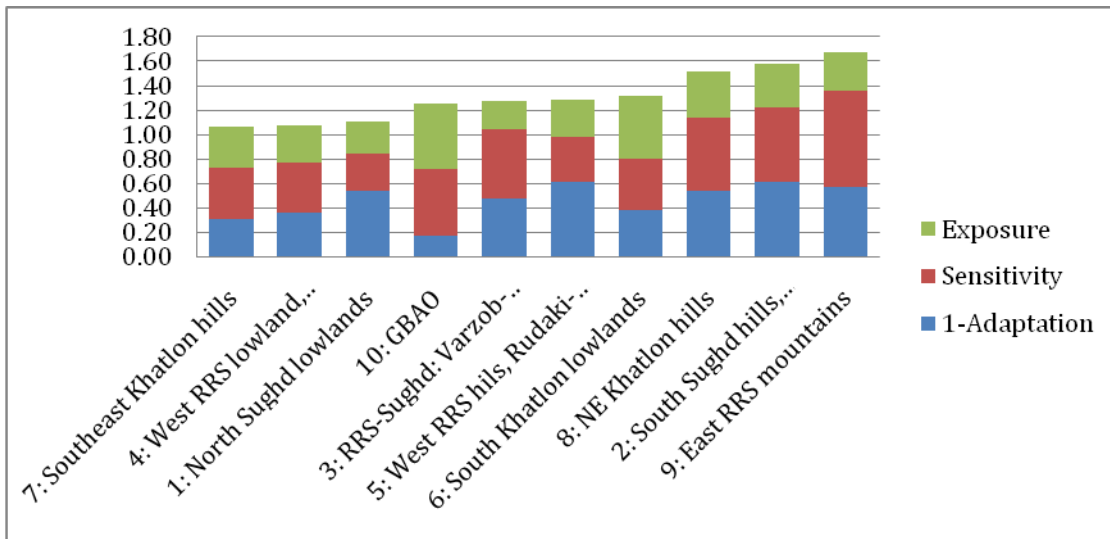


**Figure 3: Components of the vulnerability index**

Urban areas as a composite group have the lowest vulnerability, far lower than any of the rural zones. This is because urban areas have the lowest sensitivity, the second-highest adaptive capacity, and average exposure. In other words, the comparatively better socio-economic and institutional development renders urban areas less vulnerable. Compared to urban areas, all the rural zones, covering around 73% of the population, appear vulnerable.

Exposure to climate change and variability is highest in GBAO, as mentioned, as well as the South Khatlon lowlands because of their high frequency of extreme temperatures and broad range of intra-monthly temperature fluctuations. GBAO is also characterized by frequent natural disasters. Overall exposure levels are fairly uniform in the rest of the country according to these estimates (Figure 4).
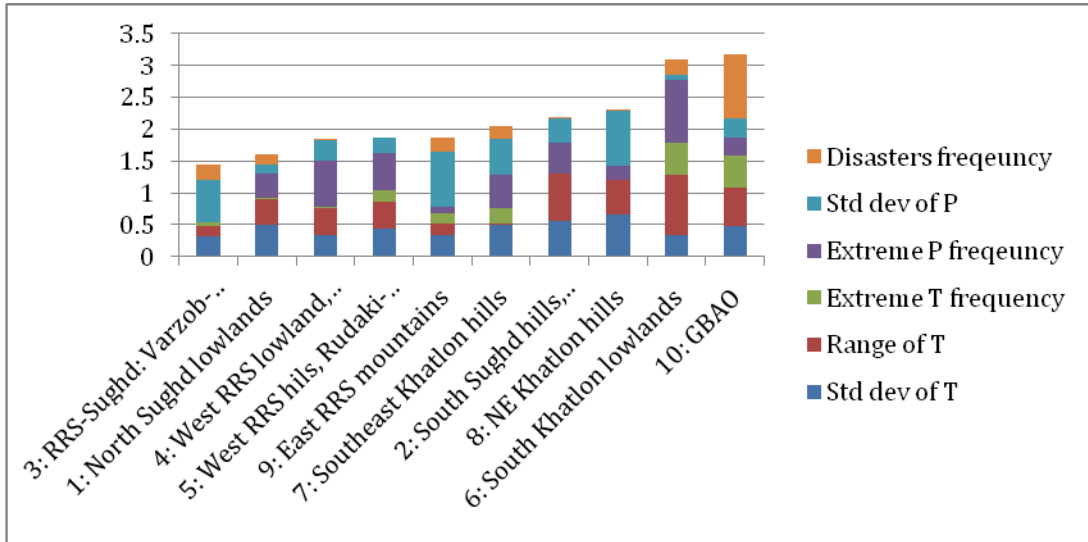


**Figure 4: Exposure index**

Sensitivity is highest in the east RRS mountain area because of the area's reliance on agriculture, high sensitivity to disasters, and widespread food insecurity (Figure 5). Sensitivity is also high in South Sughd, North-East Khatlon hills, Varzob-Zarafshan and GBAO because of disaster sensitivity and various other reasons. Rural sensitivity is lowest in North Sughd where health and disaster indicators are better and there is less exclusive reliance on agriculture.
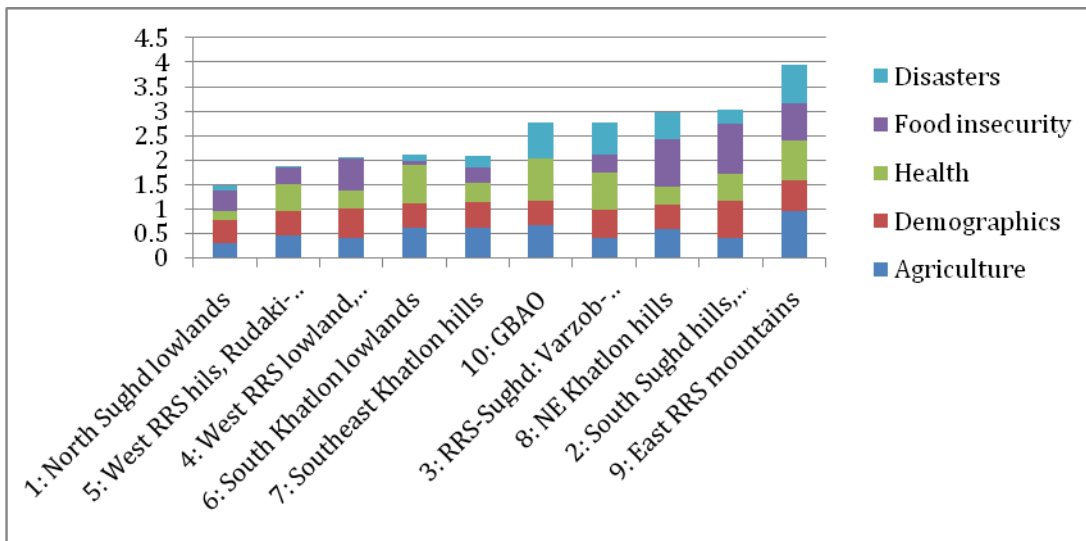


**Figure 5: Sensitivity index**

Adaptive capacity varies substantially (Figure 6). It is highest in GBAO because of its high scores on education and income diversification. Adaptive capacity is also quite strong in the South-east Khatlon hills, the West RRS lowlands, and the South Khatlon area; these areas are characterized by above-average levels of income and education.
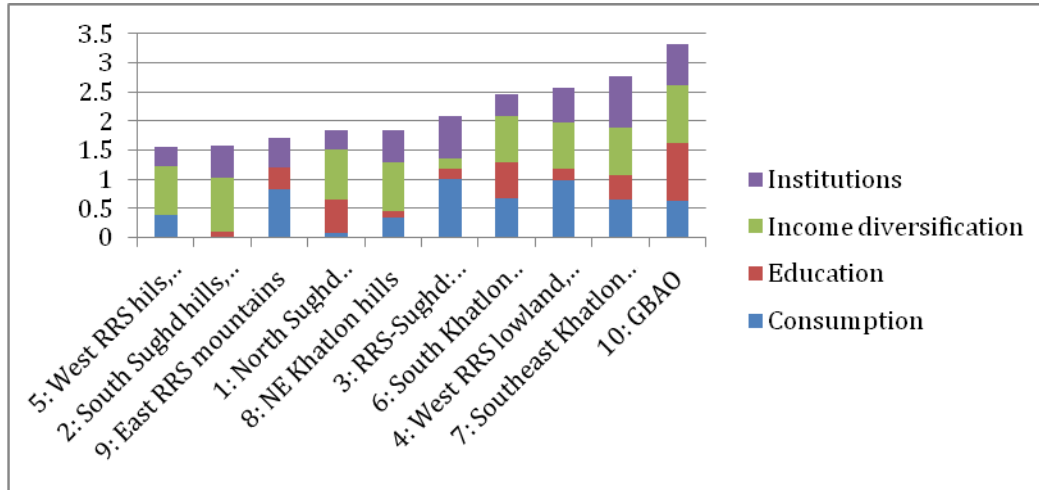


**Figure 6: Adaptive capacity**

**Results at the oblast level**

We also estimate the vulnerability index at a higher level of aggregation, that of the four administrative oblasts that make up Tajikistan (Sughd, Khatlon, RRS, GBAO). We do this for rural areas only. GBAO oblast emerges as the least vulnerable among the four oblasts, and RRS oblast as the most vulnerable (Figure 7). Again, GBAO's estimated low vulnerability to climate change is despite high sensitivity levels for almost all the measured variables (agriculture, disasters, health) which is compensated for by moderate exposure and high adaptive capacity due to income diversification from migrant remittances and high level of education among the population. In contrast, the most vulnerable RRS oblast shows high values of exposure (e.g. extremely low precipitation and temperature variation); medium sensitivity; and the lowest adaptive capacity, partly stemming from low income diversification (Figure 8).
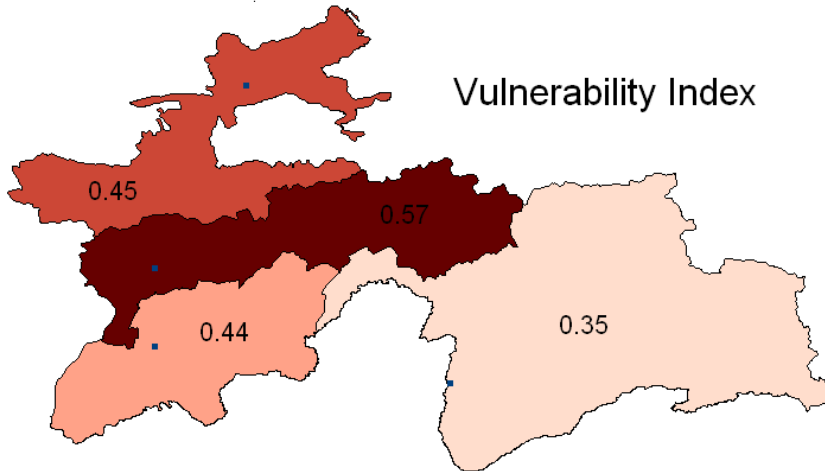
**Figure 7: Vulnerability map for Tajikistan (oblast level)**
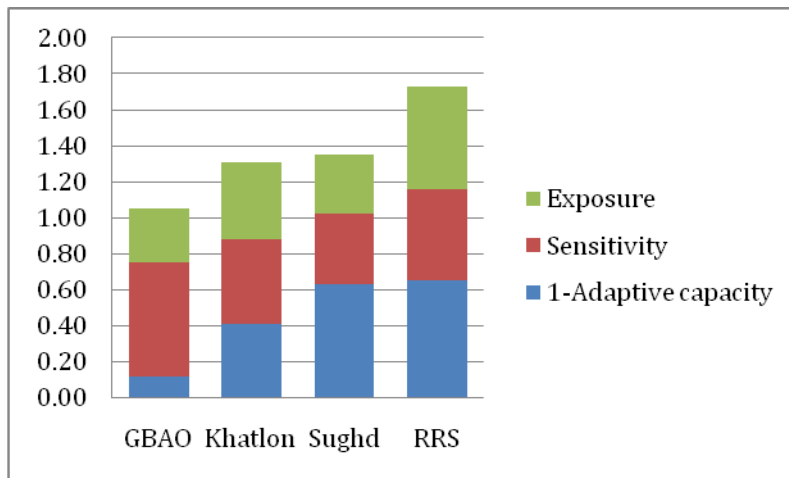


**Figure 8: Components of the vulnerability index (oblast level)**

## 5. Concluding remarks

We have constructed and presented an index of vulnerability to climate change and variability in Tajikistan. The results show that vulnerability varies according to socio-economic and institutional development in ways that do not follow directly from exposure or elevation: in climate change, geography is not destiny. The results indicate that urban areas are by far the least vulnerable while RRS oblast, in particular its eastern mountainous areas, is the most vulnerable and the remote GBAO mountains rank in the middle.

The four most vulnerable zones include the populated South Khatlon valley but not the remote and exposed GBAO mountain zone. This implies that relatively vulnerable geographic areas can overlap centers of population and economic activity. Adaptation planners therefore do not necessarily face a trade-off between defending vulnerable

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areas and defending economically important areas. These results appear aligned with certain key elements in the design of Tajikistan's adaptation program under the Pilot Program for Climate Resilience. In particular, the results lend support to the program's emphasis on agriculture and sustainable land management and on building climate resilience in major glacier-dependent river basins containing a large proportion of agricultural land, such as the Pyanj River basin in the Khatlon area (Climate Investment Funds, 2010).

The results indicate that to the extent that policy makers wish to direct funding toward areas with the highest vulnerability to climate change, they should avoid urban areas in favor of rural areas, in particular eastern RRS mountains, Southern Sughd hills, and Khatlon hills and lowlands. These are areas of varying elevation which share a high degree of sensitivity to climate change and weak adaptive capacity. These results do not tell policy makers *how* to design adaptation. The results do suggest, though, that migration to urban areas and abroad for work might usefully form part of overall adaptation strategies.

It is interesting to compare these results to a recent review of project proposals for community-based adaptation all over the developing world which found that most projects focused on rural areas, often in poor and remote parts, and rarely envisioned migration as part of adaptation (Heltberg, Gitay, and Prabhu, 2010). The results here suggest that while the rural focus is appropriate from the point of view of pro-poor adaptation, adaptation planners may want to consider the case for defending economically important rural areas and revisit the role of migration.

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**Appendix 1: Formulas and variables**

*Adaptive Capacity.*
$A = (a_1 + a_2 + a_3 + (a_4 + a_5 + a_6)/3)/4$
*where,*
*$a_1$ - household consumption per capita, LSMS*
*$a_2$ - share of population with higher education , CENSUS*
*$a_3$ - negative Herfindahl index of income diversification (higher value, more diversification), LSMS*
*$a_4$ -measure of trust (share of households having trust in people), LITS*
*$a_5$ - measure of corruption (share of households never or only raring having to give bribes), LITS*
*$a_6$ - measure of political involvement (% of households that participated in presidential elections), LITS.*

*All variables a1, a6 are normalized by linear transformation.*

*Sensitivity:*
$S = ((s_1 + s_2 + s_3)/3 + (s_4 + s_5)/2 + (s_6 + s_7)/2 + s_8 + (s_9 + s_{10})/2)/5$, *where*
*$s_1$ - negative of the amount of irrigated land per capita, LSMS*
*$s_2$ - Herfindahl index of agricultural land use diversification, LSMS*
*$s_3$ - share of household depending on agriculture (>50% of income is from agriculture), LSMS*
*$s_4$ - share of population under 5, CENSUS*
*$s_5$ - share of population above 65, CENSUS*
*$s_6$ - under 5 mortality rate, Tajikistan Statistical Agency.*
*$s_7$ - share of population with unprotected water source, LSMS*
*$s_8$ - share of population that is food insecure, LSMS*
*$s_9$ - per capita casualties from disasters, 1998-2009 MOE data*
*$s_{10}$ - per capita damage from disasters, 1998-2009 MOE data*
*all variables $s_1$, .. $s_{10}$ are normalized by linear transformation.*

*Exposure:*
$E = ((sdT_1 + ... + sdT_{12})/12 + (sdP_1 + .. sdP_{12})/12 + (rT_1 + .. rT_{12})/12 + (Nhot + Ncold)/2 + Ndry + Ndisaster)/6$,
*where,*
*$sdT_i$ - standard deviation of average temperature in month i .*
*$sdP_i$ - standard deviation of total precipitation in month i .*
*$rT_i$ - range between maxmim and minimum average temperature in month i.*
*Nhot - frequency of extremly hot months, when average temperature was higher than 30 C.*
*Ncold - frequency of extremly cold months, when average temperature was lower than - 10 C*
*Ndry - frequency of extremly dry months in the spring (less than 5 ml total precipiation) and summer (0 ml total precipiation)*
*Ndisaster - frequency of weather related disasters between 2000-2009*

*Vulnerability: $V = (A + S + E)/3$*

**Appendix 2: Composition of the geographical zones**
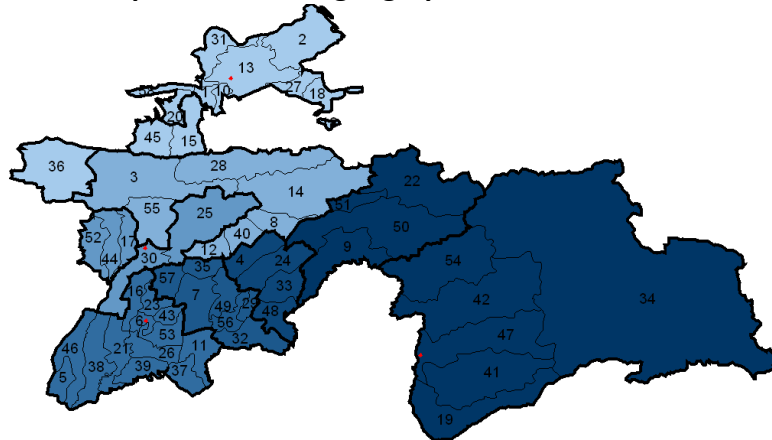


| Zone | Districts |
|------|-----------|
| 1: North Sughd lowlands | 1,2,10,13,18,20,27,31,58 |
| 2: South Sughd hills, Pedhzkent-Shakhristan-Ganchi | 15, 36, 45 |
| 3: RRS-Sughd: Varzob-Zarafshan-Surkhob | 3, 12, 14, 28, 40, 55 |
| 4: West RRS lowland, Tursunzade-Shakrinav-Gissar | 17, 44, 52 |
| 5: West RRS hils, Rudaki-Vakhdat | 25, 30 |
| 6: South Khatlon lowlands | 5, 6, 11, 16, 21, 23, 26, 37, 38, 39, 43, 46, 53 |
| 7: Southeast Khatlon hills | 7, 29, 32, 35, 49, 56 ,57 |
| 8: NE Khatlon hills | 4, 24, 33, 48 |
| 9: East RRS mountains | 9, 22, 50, 51 |
| 10: GBAO | 19, 34, 41, 42, 47, 54 |

**Table 1: Population by zone**

| Zone | Population, Census 2000 |
|------|------------------------:|
| 1: North Sughd lowlands | 994,648 |
| 2: South Sughd hills, Pedhzkent-Shakhristan-Ganchi | 297,270 |
| 3: RRS-Sogd: Varzob-Zarafshan-Surkhob | 332,803 |
| 4: West RRS lowland, Tursunzade-Shakrinav-Gissar | 392,001 |
| 5: West RRS hils, Rudaki-Vakhdat | 426,660 |
| 6: South Khatlon lowlands | 1,080,409 |
| 7: Southeast Khatlon hills | 536,901 |
| 8: NE Khatlon hills | 148,201 |
| 9: East RRS mountains | 116,528 |
| 10: GBAO | 152,041 |
| All rural | 4,477,462 |
| | |
| Urban Population | 1,620,981 |
| | |
| Total population | 6,098,443 |