Vulnerability of Water Resources to Climate Change: Analysis of Principal Factors

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1. Introduction

Available evidences obtained from global observations indicate that regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Based on the fact, the water resources are an integral part of the global hydrologic cycle, they are considered among the most vulnerable natural systems to climate changes. Therefore, it is likely to expect that a significant rate of the world population will be affected by water problems that may result in "crisis", as a consequnce of global warming.

The extent and the enormity of the problem become obvious when the role of water in agriculture is stressed in addition to its value for human life. It is essential-for coping with the expected "water crisis"- to predict the adverse effects of changes in hydrological regime as a consequence of climate change, particularly those result in extreme events such as floods and droughts, to water resources in terms of agriculture security and accordingly to human life. Research since 1996 indicate that severe problems related to water will affect the globe around 2025 which will be intensifying to attain its peak by the year 2100. Undeveloped/developing countries where semi-arid climate prevails and water resources are not properly developed will be affected most severely from climate change.

This paper outlines the approach and methodology followed in assessing the vulnerability of water resources systems to climate change in the framework of the "*Impact of Climate Changes on Agricultural Production System in Arid Areas Project (*ICCAP), a multidisciplinary project funded by RIHN-Japan and TUBITAK-Turkey.

2. Vulnerability of Water Systems

In order to establish strategies to cope with the expected problems about water resources it is essential first to define the problem in terms of vulnerability of water resources to climate changes. This requires a thorough understanding of the type and extent of the relationship between climate and water resources systems which are connected through the hydrological cycle. Water resources systems are constituted of two main part: hydrology (dynamic part) and the geological-physiographical configuration (static part).

The term "vulnerability" here is used to define the 'extent to which the water resources system is susceptible to sustaining damage from climate change' following the definition by Intergorvernmental Panel for Climate Change. Thus, *vulnerability* differs from *sensitivity* which is defined as ' the degree to which a water resources system will respond to a given change in climate, including beneficial and harmful effects'. Apparently, vulnerability is a function of sensitivity (IPCC, 2001).

3. Technical Approach & Methodology

The approach employed in the study of assessment of vulnerability of water resources to climate change is a three-phase approach. The first phase is devoted to definition of the present status. Obviously, prediction of the future requires a good knowledge of the present and the past. The second phase is the assessment of the vulnerability of the system to climate change. Analyses of all components and related parameters of the system with regard to their sensitivity to a given change in climate are achieved during this phase. The third phase is devoted to prediction of the response of the water resources systems to the given climate change scenario. This appropriate methodology required by this approach is summarized in the flowchart given Figure 1. As shown in the figure, phase-1 is represented by the construction of the "conceptual model" of the water resources system which has two main components: the geology and the hydrology. Transfer of the conceptual model to an appropriate mathematical model is the method applied to achieve phase-2. In the framework of the ICCAP, the MODFLOW and MIKE-SHE computer codes are used as mathematical models for groundwater and surface water resources respectively. After calibration of the model, related parameters are tested for sensitivity. Finally, the calibrated model is run for the vulnerable parameters for their values predicted by climate change models for different scenarios.

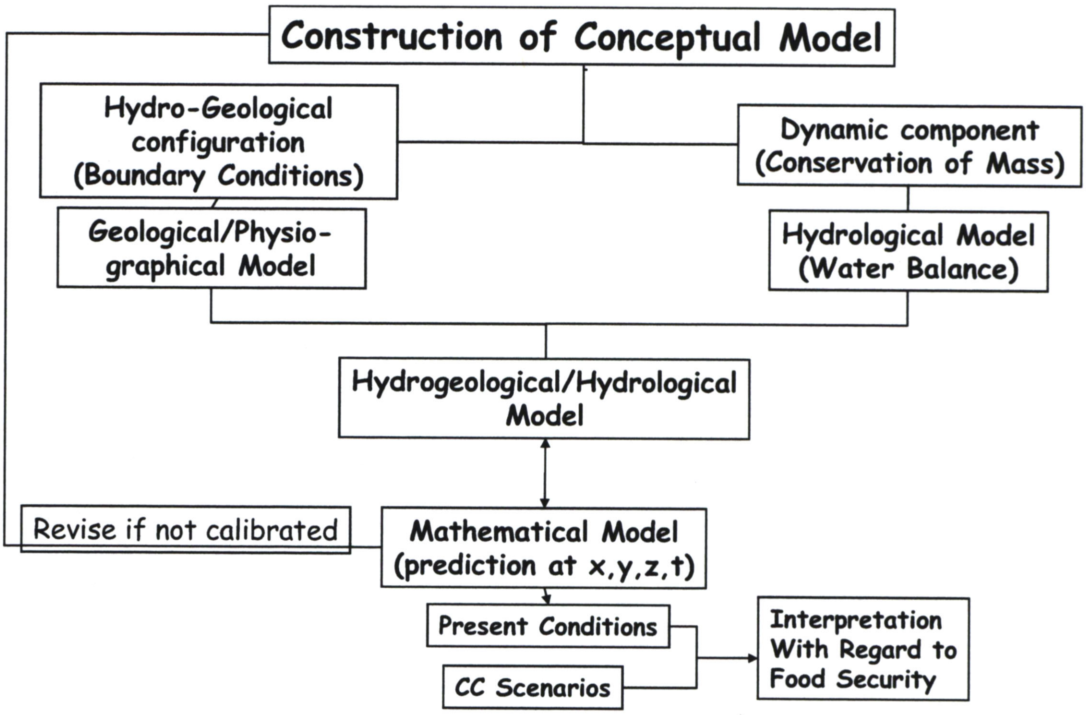

Figure 1. Methodology Applied in the Study of Assessment of Vulnerability of Water Resources Systems to Climate Change

4. Recharge Rate: Combined Effect of Physical Structure and Meteorology

Precipitation originates as evaporation from land and the oceans. Soil moisture is used by plants, which return more moisture to the atmosphere. Water that does not evaporate or transpire or seep into subsurface runs off to form streams and rivers. Snow stored in winter in the mountains provides water for rivers and deltas in the spring and summer. Groundwater constitutes one portion of the hydrologic cycle. Water seeps into water-bearing formations known as aquifers that act as conduits for transmission and as reservoirs for storage of water. Among other climatic components of the hydrologic cycle, precipitation and evapo-transpiration are the two major parameters controlling the percentage of the water that runs off over the land (surface waters) and that seeps into aquifers (groundwater). However, knowledge of climatic change alone is not adequate for assessment of the impact on the water resources. Water resources may respond quite differently to the same climatic change due to their different hydrogeological framework. Therefore, thorough knowledge of the hydrogeological setting is essential in assessing the impact of climate change on water resources. This requires the definition of the hydrodynamic system and consequently the quantification of the vulnerability of the factors governing the occurrence and movement of the water in the system. Regarding the factors having role in the occurrence and movement of the water, water resources are classified as shown in Figure 2.

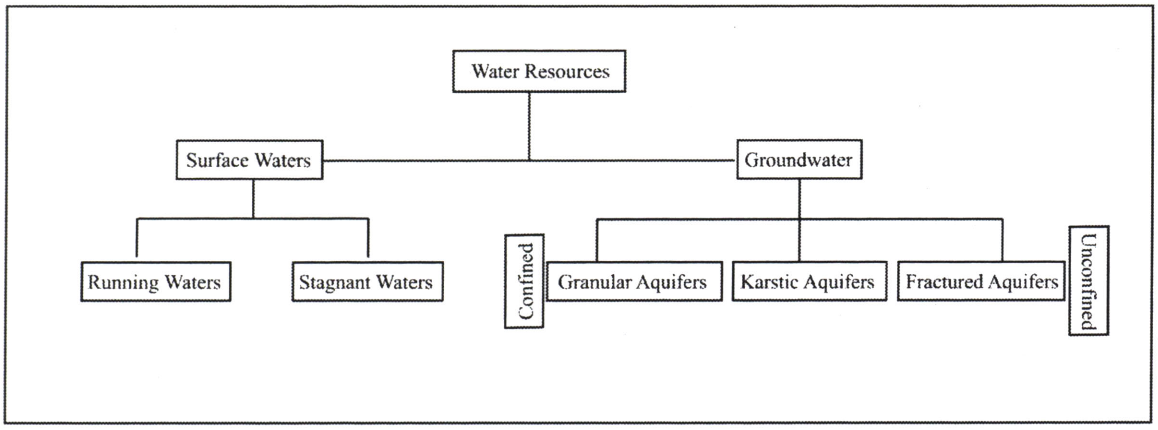

Figure 2. Classification of water resources according to the water occurrence and movement

This classification implies that the hydrological/hydrogeological structure of water resources systems should be evaluated in terms of their role in capturing and storing capability of the precipitation. Recharge mechanism is thus of major importance. This classification also implies that the relative residence or turnover time of the water resources is important in assessing the impact of change in recharge regime. Residence time of water in the system indicates to a certain extent, the time lag between the response of the system to the changes in the recharge conditions. Apparently, water resources of shorter residence time are more vulnerable to any change in the climatic conditions. As shown in Figure 3, the surface water resources require immediate attention in this respect although some specific characteristics of water resources may be more influential as they may affect the storage and discharge regime of the system. For surface water resources, size, shape, cover type, slope, drainage pattern and density of the basin and for the ground water resources, location and hydrological characteristics of the recharge area, type, depth and extent of the aquifer, hydraulic characteristics of the aquifer and the overlying vadose zone, boundary conditions of the aquifer are regarded as the important characteristics to be defined in vulnerability assessment.

Keeping in mind that each water resource has its own unique hydrogeological structure, parameters making the system more vulnerable may differ for each different system. Therefore, an accurate impact assessment first necessitates analyses of parameters for their vulnerability to climate change for each system. This is achieved by construction of a conceptual hydrogeological model which is then transferred to mathematical model of the water resources system. Once the mathematical model is calibrated for the prevailing conditions, it is possible to test every parameter used in describing the system for its response to change in recharge regime.

The recharge regime is closely related to the meteorological conditions such as the type and total amount of precipitation, spatial and temporal variation of precipitation, temperature and evapotranspiration. Recharge of water resources occurs when the water entering to the system (gain) exceeds the water leaving the system (loss). When the loss exceeds the gain, there will be no beneficial water. The major source of loss is the evaporation. Thus, the difference between precipitation and evapotranspiration (a function of temperature) can be regarded as the potential recharge and named as effective precipitation. Change in the temporal variation in precipitation and temperature due to climate change is then reflected in the effective precipitation. The ultimate consequence is the recharge of the water resources.

This effect can be demonstrated with oversimplification by the following example, taking an area where Mediterranean type of climate prevails. The total annual precipitation amounts about 600 mm. The precipitation is in the form of rain. The present monthly precipitation is distributed along the year as shown in Figure 4. The temperature distribution causes a Thornthwaite potential evapotranspira-tion (ETp) as depicted in Figure 5 where the precipitation

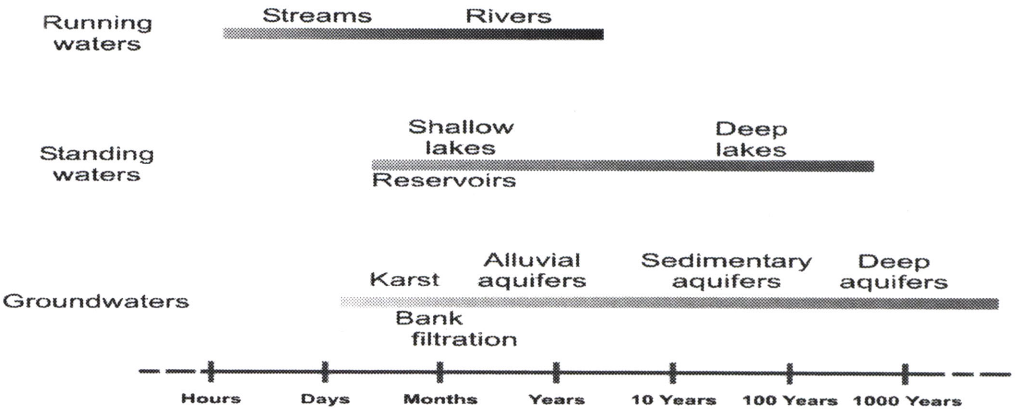

Figure 3. Residence times of water resources systems (from Chapman, 1992).

(gain) and evapo-transpiration (loss) is compared for effective precipitation. The recharge is likely to occur during winter an spring time when precipitation exceeds the ETp. All precipitation is lost during summer time when ETp exceeds the precipitation. For surface waters, runoff is expected to occur during winter and spring time. The duration of recharge lasts about six months along the period when precipitation exceeds ETp. It is possible then to state that the more evenly (uniformly) distributed precipitation the more effective precipitation, and the higher recharge rate. On the contrary, an unevenly distribution of the same amount of total precipitation causes significant reduction in the recharge rate. Figure 6 depicts an extreme example, where 600 mm. of precipitation falls in two months only. In this case, remembering that the recharge rate is limited by the infiltration capacity of the hydrogeological system and since the duration of recharge is short, recharge rate will be drastically reduced. It is apparent from Figure 6 that the most of the excess precipitation is not available for recharge of groundwater system. It is neither available for storage in hydrological basins. In this second case, the limited recharge occurs only during the first two months of the year. Figure 7 demonstrates the effect of the change in period of precipitation as a consequence of climate change. This case assumes the same amount of precipitation occurs relatively uniformly but during summer time instead of winter and spring time. The duration of the recharge may last about six months but since evapotranspiration is higher during summer time, the recharge rate is smaller than that occurs in the case given in Figure 4.

As the extreme of the extremes, an uneven variation may be accompanied by a shift of period. This case is demonstrated in Figure 8. In this case the recharge rate is even less than the case presented in Figure 6.

5.Factors Controlling Vulnerability of Water Resources Systems

As demonstrated above on some hypothetic cases, the effective precipitation has a major role in the process of making the water resources potential. The effective precipitation on the other hand, is sensitive to the changes in the magnitude, intensity and period of precipitation as discussed above. Considering these three principal factors, the impact of climate change on the effective precipitation can be evaluated together in the way shown in Figure 8. Effective precipitation is extremely low when a low total precipitation (magnitude) occurs in hot periods and in very short time (high intensity).

On the contrary, when high amount of precipitation occurs in colder periods with an even temporal variation (low intensity), then the effective precipitation is very high. Vulnerability of groundwater systems then depend upon the hydrogeological setting. In the former case, even if the setting favors high infiltration, recharge will occur in minor rate. To define the vulnerability of groundwater systems, other principal factors can be defined and related as depicted in Figure 9: effective precipitation, type of aquifer and turnover time. According to this picture, the unconfined aquifers with short turnover time are extremely sensitive to climate change and extremely vulnerable when this change reduces the effective precipitation. On the other hand confined aquifers with long residence time are much less sensitive to climate change and therefore their vulnerability is very low.

When surface waters are concerned, it is more convenient to speak about reliability instead of vulnerability. *Reliability* refers to the 'manageability of the resource with low risk'. For instance, rivers with irregular flow regime are less reliable in this sense. It is apparent that, reliability of rivers then is dependent on the basin characteristics which are all combined in a single factor called here 'time of concentration', the temporal variation of precipitation and the total amount (magnitude) of precipitation. Figure 10 shows the reliability of river basins related to climate change.

6.References

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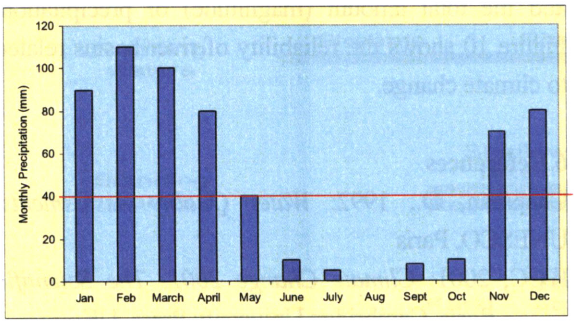

Figure 4. Temporal variation of monthly precipitation

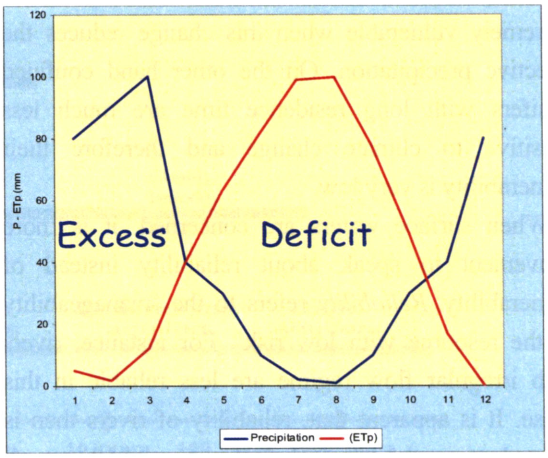

Figure 5. Comparison of precipitation and evapotranspiration

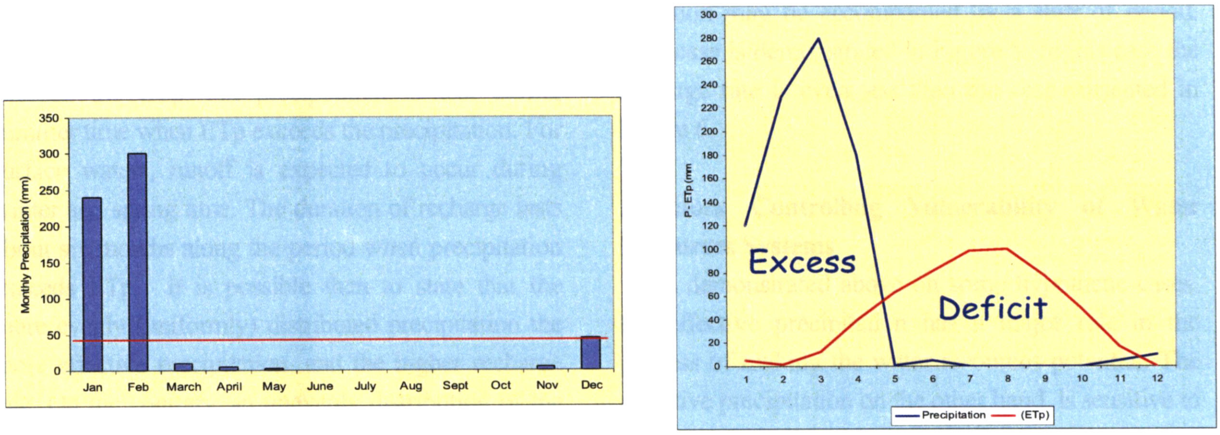

Figure 6. Unevenly distributed monthly precipitation and the corresponding excess precipitation

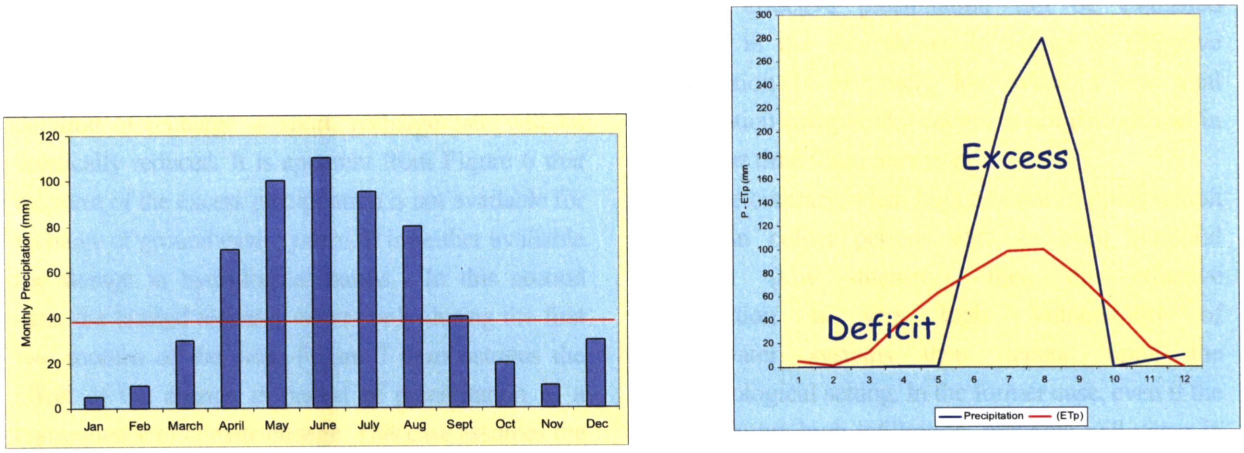

Figure 7. Effective precipitation in case of shift in period of precipitation

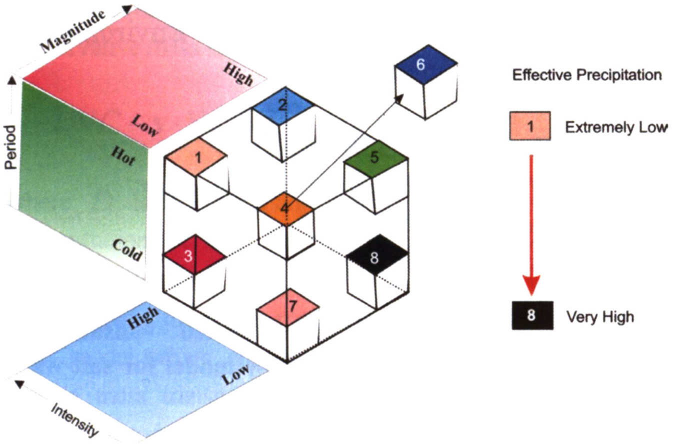

Figure 8. Principal factors controlling effective precipitation

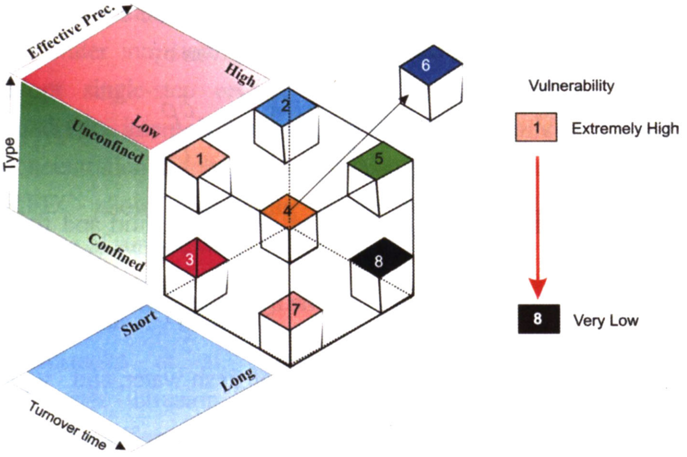

Figure 9. Principal factors controlling vulnerability of groundwater systems to climate change

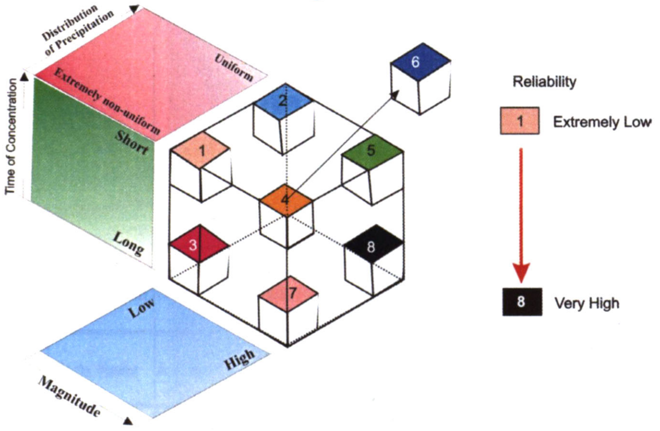

Figure 10. Principal factors controlling reliability of surface waters to climate change