Conceptualizing risk assessment framework for impacts of climate change on water resources

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This article offers an inventory of the risk of potential hazards to water resources and its implications to human and ecological receptors that may result from the climate change with special reference to India, a developing country. It is a study-based approach analysing various studies undertaken earlier in the field of risk assessment and works out afresh a framework on the basis of these studies to assess risk to water resources as an outcome of climate change. A schematic framework has been prepared for characterization of risk components and for attempting risk assessment. This article has applied value for preliminary assessment of risk factors contributing to any harm to water resources. This framework can also be applied to an assessment of risk vulnerability to smaller water bodies and to catchment-level studies. The study helps in conceptualizing an issue and leaves an open end from where this issue can be taken up for further research and applications.

Keywords: Anthropogenic activities, climate change, risk assessment, water resources, urban development.

WATER is finite in quantity, tangible in nature, and unequally distributed throughout the world. Only 2.5% of 1386 million cubic kilolitres of water available on earth is freshwater and only one-third of this smaller quantity is available for human use[1]. Total water drawn globally for human use has almost tripled in the last 50 years and is projected to increase even further by 2025 (ref. 2).

Recent research has identified the need to conserve 20–60% of fresh surface water supplies to maintain ecosystem functions and to ensure sustainability of the natural resources[3].

Looking into the many challenges to water resources, including climate change, anticipating sustainability of water resources is of great importance. Over the past decade, evidence on global warming and the accompanying changes in the earth is mounting. The IPCC's fourth assessment report concludes that it is 90–99% likely that the rise in global atmospheric temperature since the mid-19th century has been caused by human activities[4].

For India, the future projections using climate models point to an increase in the monsoon rainfall in most parts of the country. They also show an increase in greenhouse gases and sulphate aerosols[5].

'Both present variability and long-term climate change impacts are most severe in the developing world, the segment of world that is least able to buffer itself against impacts. The impacts are particularly severe in countries, regions and communities where the capacity to cope with, and adapt to, the hydrological effects of climate variability will influence their overall development prospects'[6]. The implications of climate variability and climate change have not been fully taken into account in the current decision-making framework[7]. Therefore, assessment of vulnerability and consequent risk to water resources due to climate-change impacts is necessary to work out proper adaptation and mitigation responses. The overall purpose of such an exercise is two-fold: one, to define the environmental and ecological consequences of the disturbance in the water cycle and water resource system, and two, to anticipate the impacts on the human system at large.

Risk is a measure of the probability of an adverse effect that might occur. Risk to water resources due to climate change can be defined as 'the potential hazard to water resources and its implications on human and ecological receptors that may result from the climate change'[8]. Risk assessment is a complex exercise involving evaluation of the hazards to the vulnerable sectors and acts as a key in developing future risk management policies. It involves: (a) Assessing the risk to a system; (b) Calculating and equipping for emergency (preparedness) and, (c) Addressing mitigation issues.

Thus risk assessment aims to reduce the probability of reaching levels of impacts to which we cannot adapt.

Climate change, water resources and risk

Through increasing surface temperatures, and changing rates of precipitation and subsequent evapo-transpiration, climate change will influence the hydrological (water) cycle[9]. The impact of climate change on freshwater resources according to the fourth assessment report of the IPCC[4] is given in Table 1.

The importance of viewing climate variability as a crucial ingredient of water resource management has been clearly demonstrated by O'Connell and Wallis[10]. Climate

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Table 1. Impact of climate change on freshwater resources

Sector	Region/conditions	Impact	% Change	Degree of confidence
Freshwater resources and management	High latitude, some wet tropical areas	Increase in annual average river run-off and water availability	10–40	Very high
	Dry regions at mid-latitudes and in the dry tropical areas, some of which are presently water-stressed	Decrease in annual average river run-off and water availability	10–30	Very high
	Drought-affected areas	Increase in extent	–	Very high
	–	Increase in frequency of heavy precipitation events	–	Very high Very high
	Regions with supply of melt water from major mountain ranges. (Impacting one-sixth population of the world)	Decline in water supplies stored in glaciers and snow covers		

IPCC[4].

variability has always existed and shall continue to exist. Accordingly, the variability factor should be recognized, analysed and used in the process of water resource planning and management. Here, what is important for planners today is to capture the major shifts in the climate and incorporate them accordingly in future designs.

The study of service for urban areas is in an embryonic state and the potential impact of global environmental change on service has not been fully incorporated. For example, the urban corridor in southern California and northern Mexico (Los Angeles, Orange County, San Diego, Tijuana and Rosarito) depends on water imported from northern California and the Colorado River. These already stressed watersheds can be significantly affected further by climate change. Some studies depict a potential decline of up to 10% of water in the Colorado River under certain global warming scenarios[11,12]. Water supply in urban southern California in future, therefore, could face difficult challenges under such scenarios. Similar potential long-term impacts were defined in a study of climate change in the New York metropolitan region[13]. A climate change impact study on the Ganga–Damodar Basin in India predicts decreased river flow in the sub-catchments of Talaiya, Konar, Maithon, Panchet and Durgapur[14]. These studies indicate that the water supply may be adversely affected by climate change during the 21st century.

A significant number of urban areas currently face similar challenges to fulfilling the demand of critical natural resources (water, energy, food, etc.). This illustrates the strong need for a better understanding and knowledge of the state of these resource pools, how they are likely to be impacted by global environmental change, and the probable consequences of those impacts upon urban areas[6].

The risk to water resources is, thus, two-fold and is illustrated in Figure 1.

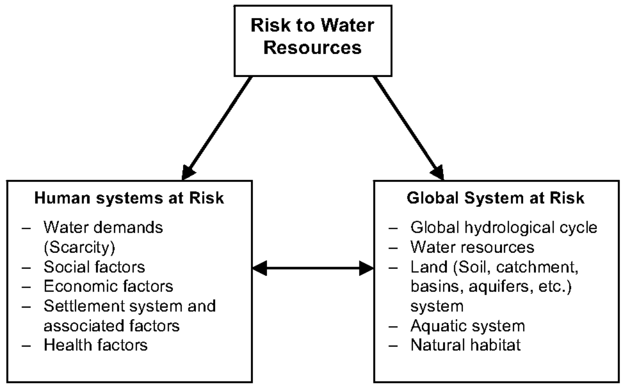

Figure 1. Relationship between risk and water resources.

Risk assessment in practice – need and method adopted

The need

The need for the risk assessment exercise for water resources from an environmental economic approach is highlighted by Mukherjee[15]. The author explores the avenues of risk management in water resource, particularly for India, and asserts that, due to critical qualitative and quantitative problems related to the prevalent water management systems, risk assessment of other options is the demand of the day. In reference to the unchecked urban development and urban pockets causing complex situations environmentally, the author presents in her study an analytical approach for validating future proposals and emphasizes risk assessment. According to Kabat *et al.*[16], 'The need is to access a platform that bridges the information gaps between the water and climate sectors in order to improve our capacity to cope with the impacts of increasing climate variability and change on water management.' The outcome of the study is that adaptation and coping measures are scale-dependent and may vary temporally and spatially. Kabat *et al.*[16] specify that the problem related to water will be mainly confronted by the developing countries, looking at their present vulnerabilities and current problems.

Mays[17] has highlighted the role of risk analysis to water resources using an uncertainty approach and composite risk analysis for water resources and water systems. Georghe[18] has highlighted the need for prioritization of risks at the regional level and has targeted risk when developing scenarios for risk analysis at the regional level, including people, ecological systems, and water systems.

Methods for risk assessment

The IPCC assessment[19] reviews the current state of risk management techniques across sectors, including water. Frederick *et al.*[20] have presented an analysis of climate change and water resource planning criteria from a variety of theoretical and applied perspectives. One good example of a method adopted for risk assessment of water resources is in the Daly River basin of northern Australia. The risk assessment aims at a larger assessment of environmental flows of the basin and adopts quantitative risk analysis methods[21].

A team of scientists from the Stockholm Environment Institute, Oxford Center, have carried out particularly notable work on risk analysis and vulnerability assessment and adaptation. In their technical paper, Downing *et al.*[22] have discussed the management of risks posed by climate change, including climate variability. They have proposed the identification and characterization of anthropogenic and natural systems that are sensitive to climate and describe them as a key input for targeting, formulating and evaluating adaptation policies. In particular, they have addressed the following:

- The extent of anticipated benefits from existing development projects sensitive to the risk of climate change, and
- Ways to consider future climate risk in the design of development projects.

Jones *et al.*[23] have mentioned two approaches to climate-related risks, one being a natural hazards-based approach and the other a vulnerability-based approach. They favour the vulnerability-based approach for most of the climate-related impacts, including water. Further, they state that a dynamic understanding of future risk requires knowledge of both biophysical and socio-economic change[23]. Socio-economic analysis can be used to describe change in human systems that will affect a group's ability to cope with future climates. Another study highlights the use of risk-assessment methodologies, including statistical analysis, to link independent and dependent relationships between critical and complex systems like climate change[24].

Thus, a conclusion drawn from these studies is that there should be a prior understanding of the following factors:

- The interrelationship and interdependencies of factors such as urban development, urban demand, water stress, anthropogenic activities, climate change and water resources.
- The sensitive areas and the type of damages to which a system is prone.
- Detailed study of the interrelationship of various vulnerabilities and the associated risk.
- The outcome in the system in question (hydrological cycle in general and water resources in particular).

Generalized framework for calculation of risk

A risk assessment programme needs to be devised to provide a framework for considerations, which are to be worked out in a schematic and systematic manner. This involves the following:

- Climate change and the criticalities (attributes) to water resources (impact of climate change such as some degree of loss to water resources) need to be worked out and quantified.
- Threats to water resources need to be characterized (indicators).
- The vulnerabilities of water resources becoming potential threats due to climate change are interrelated and need to be finally worked out and analysed.

This exercise entails the following steps:

- Vulnerabilities of water resources need to be worked out.
- Risk factors to water resources also need to be worked out.
- Resultant risks have to be assessed and ranked.
- Possible mitigation options to reduce vulnerabilities (and thus risks) need to be identified, and
- Appropriate options need to be selected and implemented to achieve an acceptable level of risk at an acceptable cost.

Based on the above study and derived information thereof, a detailed framework (schematic) is given in Figure 2. This framework is helpful for understanding in a systematic manner, the following:

(a) Criticalities of the phenomenon of climate change.
(b) Threats to water resources.
(c) Associated vulnerabilities.

This is particularly useful to work out in advance the risk involved and its components. One can further move onto

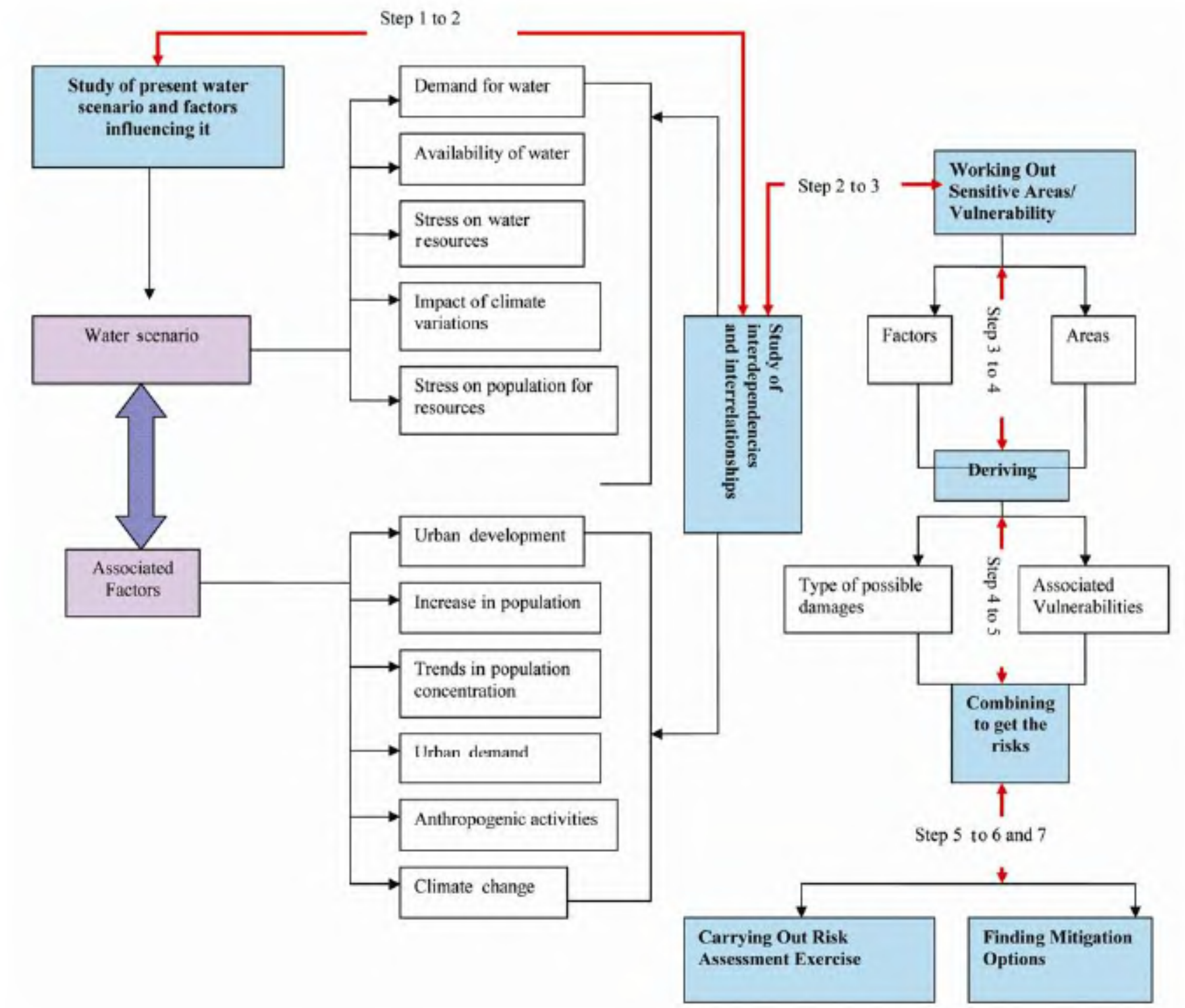

Figure 2. Schematic framework for risk components characterization and risk assessment preparation.

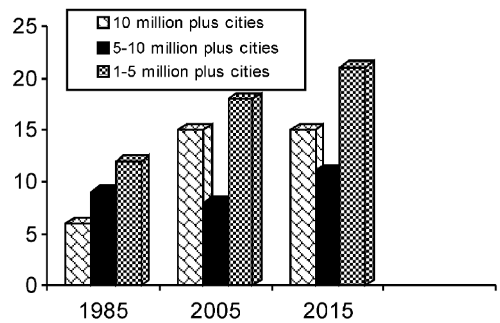

Figure 3. Percentage of urban population in India according to size and class of the cities. Source: www.infochangeindia.org

the exercise of assessment of risk and possible mitigation directions from this point. Now this schematic framework when applied in the context of the case example taken for the present study, will have the working sequence given in Figure 2.

Urbanizing India

The issue of climate change and urbanization is important to India because of the rising pressure of population directed towards the cities. Trends of urbanization in India for the last 50 years show that the number of urban centres has nearly doubled from 1961 to 2001. The urban population has also increased manifold in the last 50 years; from 78,936,603 in 1961 to 217,611,012 in 1991 and 285,354,954 in 2001. The percentage of urban population to total population has increased from 17.97 in 1961 to 27.8 in 2001 (Census 2001; Figure 3)[25].

In India there are more than 250 million city-dwellers. According to the predictions made by the UNHABITAT[26], this number will rise even further, and by 2020, about 50% of the population in India will be living in the cities. When this happens there will be more pressure on the already strained centralized water-supply systems of the urban areas. The urban water supply and sanitation systems in the country are already suffering from inadequate levels of service, an increasing demand–supply gap, poor sanitary conditions and deteriorating financial and technical performance (source: www.rainwaterharvesting.org/crisis/urbanwater).

India climatic conditions and influence of climate on water resource

India has a climate-dependent economy. The preliminary assessment of the IPCC[9] has revealed that under the GHG scenario, the severity of droughts and intensity of floods in various parts of India are projected to increase. Also, a general reduction in the quantity of available run-off has been predicted in these studies.

India predominantly has a tropical monsoon climate. It is a characteristic feature of the tropical monsoon climate that rainfall occurs for only a short spell during the rainy season with most other periods of the year being dry[27]. Therefore, in India, the water that is stored (in the rainfed rivers and groundwater percolation, etc.) has to be used for the whole year till the next rainy season. Thus, the failure of the monsoon or any adverse effect on the monsoon, as well as high temperature, significantly affect the daily and yearly demand of water.

Besides this, climate change-induced glacier melting contributes to flows in the rivers during the dry season[27]. Thus, climate plays a decisive role in water resource availability in India.

India water availability and water demand

According to the National Water Policy of India[28], 'Out of the total precipitation, including snowfall, of around 4000 billion cubic meters in the country, the availability of water from surface water and replenishable ground water is put at 1869 billion cubic meters. Because of topographical and other constraints, about 60% of this, i.e. 690 billion cubic meters from surface water and 432 billion cubic meters from ground water, can be put to beneficial use.'

In Indian conditions, the availability of water is highly uneven in both space and time. The total average annual flow per year for Indian rivers is estimated as 1953 km^3. The total annual replenishable groundwater resources are assessed as 432 km^3. The annual utilizable surface water and groundwater resources of India are estimated as 690 and 396 km^3 per year respectively[29]. With rapid increase in population and improved living standards, the pressure on our water resources is also increasing, while availability of water resources is declining day by day. Due to spatial and temporal variability in precipitation, the country faces the problem of flood and drought syndrome. Overexploitation of groundwater is leading to low flows in the rivers, declining of the groundwater resources, and salt-water intrusion in aquifers in the coastal areas. Unrestricted irrigation through the canal system in some of the command areas has resulted in waterlogging and salinity. The quality of surface and groundwater resources is also deteriorating because of increasing pollutant loads from point and non-point sources. So far, the major consumptive use of water has been for irrigation. The gross irrigation potential is estimated[28] to have increased from 19.5 million hectare (m ha) at the time of independence to about 95 m ha by the end of the period 1999–2000. Further development of irrigation potential is required, keeping in view that the population is expected to reach around 1390 million by 2025.

Production of foodgrains has increased from around 50 million tonnes (mt) in the 1950s to about 208 mt in the period 1999–2000. This will have to be raised[28] to around 350 mt by the year 2025. The drinking-water needs of people and livestock also have to be met. 'Domestic and industrial water needs have largely been concentrated in or near major cities. Demand for water for hydro and thermal power generation and for other industrial uses is also increasing substantially. As a result, water, which is already a scarce resource, will become even scarcer in future. Climate change and its projected implications would add to this already grave condition in India. Such a situation underscores the need for utmost efficiency in utilization of water and public awareness of the importance of its conservation and management, besides attaching utmost importance to adaptation and mitigation issues as far as climate change as an individual issue is concerned.'[28]

According to the international norms, if per-capita water availability is less than 1700 m^3 per year then the country is categorized as water-stressed and if it is less than 1000 m^3 per capita per year, then the country is classified as water-scarce. In India, per capita surface water availability in 1991 and 2001 was 2309 and 1902 m^3 respectively, and these are projected to reduce further to 1401 and 1191 m^3 by the years 2025 and 2050 respectively[29]. Hence, there is a need for proper planning, development and management of the greatest assets of the country, namely water and land resources, for raising the standards of living of the millions of people.

Climate change and Indian water resources

'Under a changed climatic regime for any given region in India, the combined effect of lower rainfall and more evaporation would have dire consequences. Both these would lead to less runoff, substantially changing the availability of freshwater in the watersheds. Also, poten-

Box 1. Impacts on water resources of India due to climate change

- An assessment of the implications of climate change for hydrological regimes and water resources using scenarios developed from Hadley Centre model simulations indicates that by the year 2050, the average annual run-off in the river Brahmaputra will decline by 14%.
- Global average sea-level will rise by 0.1–0.2 m in the 20th century and will rise by 0.09–0.88 m by 2100.
- The share of ice-melt in sea-level rise is increasing, and will accelerate if the larger ice sheets crumble. As mountain glaciers shrink, large regions that rely on glacial run-off for water supply could experience severe shortage. In northern India, a region already facing severe water scarcity, an estimated 500 million people depend on the tributaries of the glacier-fed Indus and Ganges rivers for irrigation and drinking water. But as the Himalayan glaciers melt, these rivers are initially expected to swell and then fall to dangerously low levels, particularly in summer. (In 1999, the Indus reached record high levels because of glacial melt.)
- The Dokriani Bamak Glacier in the Himalayas has retreated by 20 m in 1998, compared with an average retreat of 16.5 m over the previous 5 years.
- In the absence of protection, a 1 m sea-level rise on the Indian coastline is likely to affect a total area of 5763 km^2, and put 7.1 million people at risk.
- Climate change will cause decline in groundwater levels, while rising sea levels will salinate freshwater sources.
- Agriculture in the coastal regions of Gujarat, Maharashtra and Karnataka will be the most negatively affected. Losses are also indicated for the major foodgrain-producing regions of Punjab, Haryana and western Uttar Pradesh.
- Increased temperatures will also lead to an increase in pest populations and resultant crop loss.
- Vector-borne diseases, such as malaria, are likely to invade new areas, including the highlands, as temperatures increase in these regions, making for more conducive conditions for vector populations to thrive.
- More people, particularly the poor, homeless, aged and children, will succumb to or suffer from heat strokes.
- Water-borne diseases and diseases caused by malnutrition will increase due to loss in agricultural productivity.

tial changes in temperature and precipitation might have a dramatic impact on the soil moisture and aridity level of hydrological zones. With changes in the flows, annual runoff, and ground water recharge, water available for usage will further be decreased.'[30] A compilation of some of the regional impacts from studies conducted so far is given in Box 1.

India's vulnerability towards water resources and its relationship with the issue of climate change

Vulnerability to long-term climate change is not evenly distributed across regions and social groups in India. Vulnerability is influenced by both physical and socio-economic characteristics. These characteristics are not static. The dynamics of vulnerability is changing as India deregulates the domestic economy, liberalizes international investment and trade policies, and implements fiscal stabilization policies. Such measures are intended to create an appropriate incentive structure for increasing agricultural production, but at the same time they are changing vulnerability to climate variability and long-term climate change.

A detailed account of the vulnerability of India and its water resources has been prepared. The framework relates the components of climate change to water resources (Figure 4). Figure 4 gives the vulnerabilities as preconditions peculiar to India. It also shows the factors associated with climate change which may hamper the water availability scenario in India.

Further, it gives the relationship of the combined factors of the two issues (climate change and water resources) for which mitigation and adaptation measures will have to be worked out. It also gives an account of those who will be affected by these mitigation and adaptation measures, relating them with the potential victims (vulnerable class) as well as the beneficiaries. To complete the cycle it shows the dependency of the victims with the preconditions prevailing in India.

Characterizing risk for India and its water resources

The framework for risk characterization (Figure 2) and the representation of relationship of Indian vulnerability (Figure 4) have been developed into a working cycle for risk characterization (Figure 5). The steps involved are listed below.

- Study the human system, climate and hydrology of India.
- Follow trends in this respect.
- Work out indicators and related attributes.

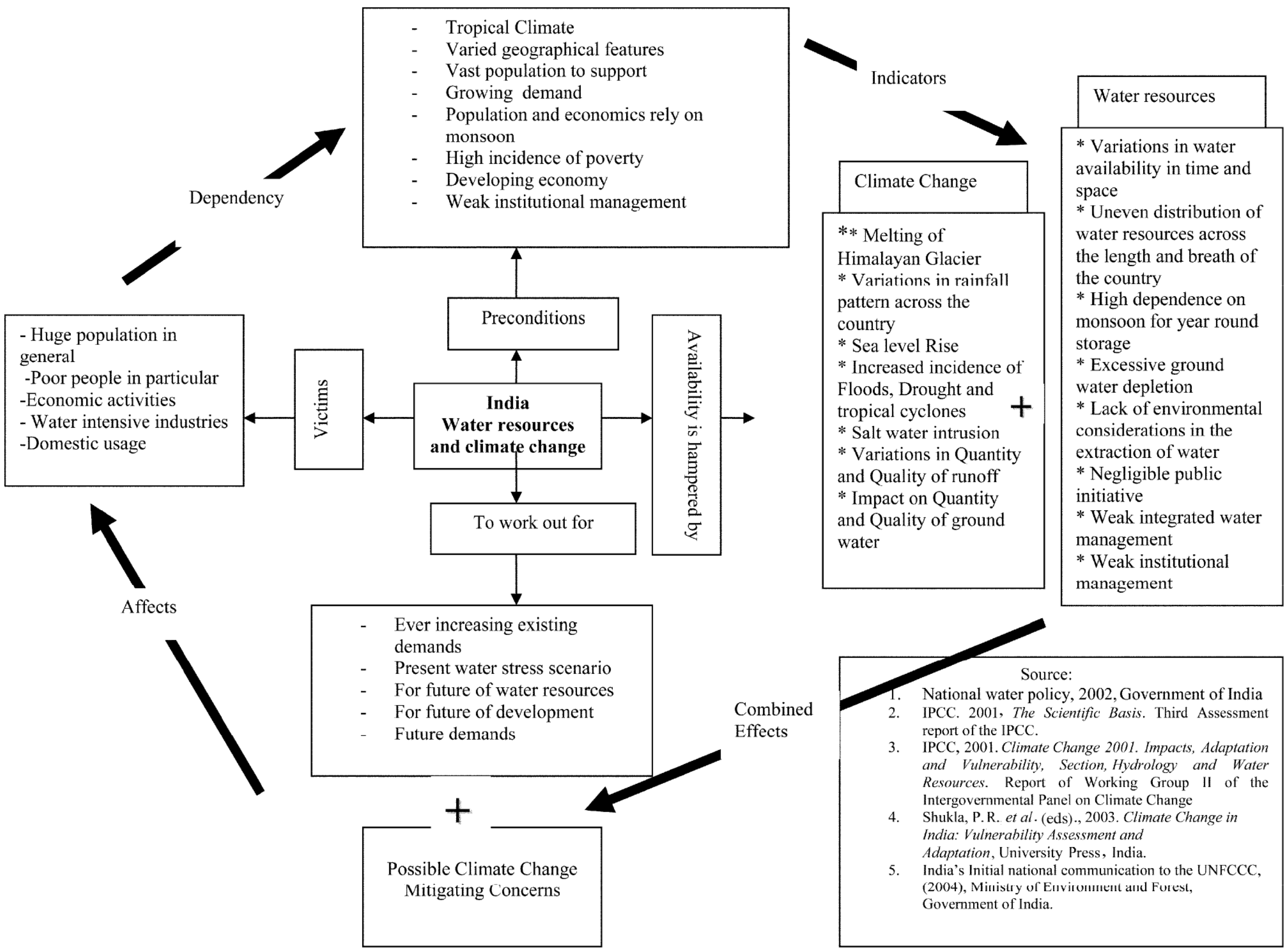

Figure 4. Relationship between the water resources and climate change in India.

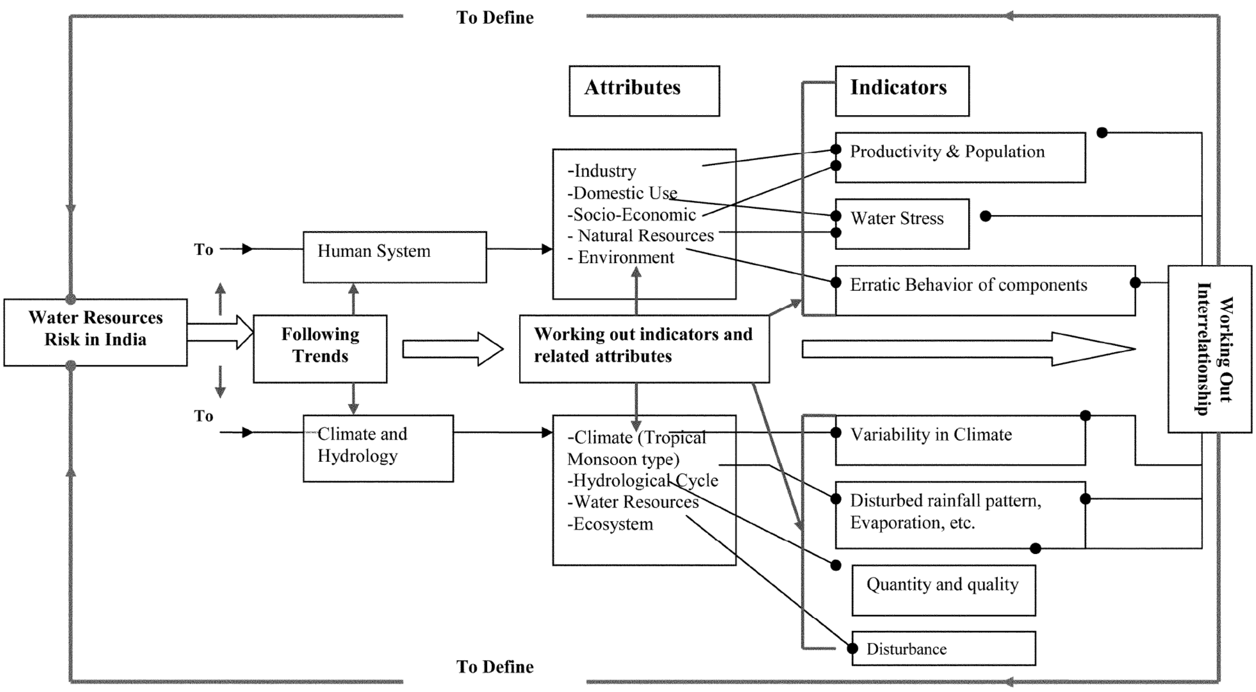

Figure 5. Working cycle of risk characterization while assessing risk to water resources due to climate change.

- Work out the relationship between the indicators and attributes.
- Define risks using these interrelationships.

This will involve studying the risk to water resources, keeping in mind the risk to:

(i) Human system (demographic features and associated functions affected by the threat).
(ii) Climate and hydrology (peculiarities of climate and hydrology in Indian conditions that make the water resources vulnerable).

Further down the line, the past and future trends related to the two systems (human and climate/hydrology) should be worked out using the available data, generating models of the future scenarios and projection methods, wherever required.

The next step would be to analyse and develop the related attributes and indicators that are being affected by any change in water resources, particularly due to change in climate. This will provide a base to workout the interrelationships of all the attributes and their indicators, and to define the same in terms of the risk to water resources.

Conclusion

This article is a conceptual study about calculating and assessing risk to water resources due to climate change.

Three framework have been presented here, i.e.

1. Schematic framework for risk components characterization and risk assessment preparation.
2. Representation of the relationship, the water resources and climate change in India.
3. Working cycle of risk characterization while assessing risk to water resources due to climate change.

Using these one can proceed stepwise to understand the interrelationship of all the components responsible and affected by the possible change in water resources due to projected climate change in India. The detailed framework thus achieved can be placed against weightage exercises and projections/models for scenario development to define the risk to water resources in general. Taking one attribute at a time, the quantitative risk assessment can be carried out.

The typical character of the tropical monsoon climate, unique geographical features, development status and huge population are the characteristic features that define the face of the future environment and the status of natural resources in India[7]. When it comes to the added pressure of climate change, and particularly its impact on finite and indispensable resources like water, the situation calls for immediate attention. The need of the hour is to analyse the potential threats and risks to the human system as well as the environment.

Risk assessment is a science in itself. It involves the use of temporal and spatial data of various hydro-meteorological variables. However, in India, the network for monitoring these variables is inadequate. In addition, data collection, processing, storage and dissemination are not well-organized[29]. Therefore, there is need for a comprehensive, reliable and easily accessible Hydrological Information System (HIS) to be able to complete a risk assessment exercise. To achieve these objectives, there is a need to strengthen the existing monitoring network of data and develop the HIS by improving the data processing, analysis and dissemination techniques through proper coordination amongst the various agencies.

A World Bank-aided Hydrology Project Phase-I (HP-I) has been launched to improve the HIS for India. During the HP-I, the data-monitoring network has been strengthened and HIS has been developed for various river basins of the nine peninsular states of India, viz. Andhra Pradesh, Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Kerala, Orissa and Tamil Nadu. This information system will be useful for processing, storage and dissemination of the reliable and spatially intensive data on water quantity and quality in computerized databases[29].

Climate change is posing a challenge to the existing water resources and to those who are responsible for the management of the water resources. Hydrological studies are required to be taken up for assessment of water resources under changing climatic scenarios. For predicting the future climatological variables on micro-, meso- and macro-watershed scales, a comprehensive general circulation model is required to be developed for India, giving due consideration to the global scenario.

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