# Developing a Composite Index for Assessing the Climate-Induced Risk in Water and Sanitation in Maharashtra

Institute for Resource Analysis and Policy

## 1 Background

Climate risk is composite of hazard, exposure and vulnerability (WMO, 2014). The degree of risks in water supply and sanitation induced by climate variability and change depends on a variety of natural, physical, social, economic, and institutional factors. Reducing the exposure and vulnerability and also strengthening the capacity of the system and the communities to adapt will increase resilience to potential adverse impacts of climate induced risks. For climate-resilient development of WASH programmes in any locality, understanding the various factors influencing the climate risks and the local contexts in relation to these factors are extremely important (source: based on UNICEF & GWP, 2014; UNICEF, 2016).

This note presents a framework for developing the composite index to assess the overall 'climate-induced risk' in water and sanitation, which captures the degrees of hazard, exposure and vulnerability. The framework captures the following: a] natural (hydrology, climate, geology and topography) factors affecting the degree of occurrence of climate hazards in different regions; b] physical factors (types and characteristics of water and sanitation infrastructure) influencing both the magnitude of climate-induced hazard and the exposure of the communities to these hazards; c] socio-economic factors determining the exposure of the entire WASH system and vulnerability of the communities to hazards; and, d] institutional factors influencing the exposure, and vulnerability of the communities to climate induced hazards in water and sanitation.

This is based on extensive review of international scientific literature on the various factors influencing:climate related hazards in water and sanitation; the degree of exposure of the WASH system to such hazards; and the vulnerability of the communities to the hazards to which they is exposed.The literature review also explores the manner in which these factorsinfluence the degree of climate related risks in water and sanitation.Based on this framework, the development of a composite index for assessing climate related risks in WASH is in its advanced stage, and the same is presented in this note. Once the index is refined, the values of this index would be computed for two distinct 'regions' of Maharashtra, i.e. Marathwada and Vidarbha, each one characterized by a unique natural, physical, socio-economic and institutional characteristic.

## 2 Literature Review

The review has been grouped under two themes: 1] regional scale studies on impact of climate risks for WASH sector; and 2] development and application of various vulnerability indicesto assess the risks of climate related hazards.

### *2.1 Climate Risks Study and WASH*

**A] Climate threats, Water Supply Vulnerability and the Risk of a Water Crisis in the Monterrey Metropolitan Area (North-Eastern Mexico) (Sisto et al, 2016)**

The study evaluated the risk during an event of sudden reduction in water supply in the Monterrey Metropolitan Area, which is posed by climate threats and the vulnerability of its water supply system. The authors used the long-term precipitation, water supply, and water availability data to show that the region is subject to recurring period of exceptionally low precipitation and scarce surface water availability. They also identified that during 1998-2013, the water supply system has almost collapsed as reservoirs have deficient water due to abnormal dry weather condition. Precipitation data was used to compute the Standardize Precipitation Index (SPI), to detect exceptionally dry or wet periods in the history. The Net Volume Index (NVI) was used to analyze vulnerability of the water supply systems by measuring the utilization rate of the system's effective storage capacity at a particular point in time. The authors argued that increased reliance on surface sources may have enhanced the water supply system's exposure to climate hazard as surface sources were r more sensitive to climate variability than groundwater resources, especially in the short term as low precipitation often results in scarce surface runoff and reservoir inflows. Thus there is an existence of a substantial water crisis risk in the region due to climate variability and the vulnerability of its water supply system. Moreover climate change will probably intensify this risk, while continued growth in the region will keep amplifying the consequences of a future water crisis. The authors concluded that the risk associated with water shortages would increase in future due to climate change.

**B] A Review of Multi Risk Methodologies for Natural Hazards: Consequences and Challenges for a Climate Change Impact Assessment (Gallina et al, 2016)**

The study reviewed existing risk assessment methodologies for different types of risks, applied by different organizations for development of a single multi-risk methodology for climate change. This study reviewed different research studies related to the assessment of multiple natural hazards (e.g. flood, storms, droughts etc.) affecting the same region in different time periods. This study mainly focused on the identification of multiple hazard types using different quantitative and qualitative approaches. The study revealed that different methodologies assess the vulnerability of multiple targets to specific natural hazards by means of vulnerability functions and indicators at the regional and local scale. The overall conclusion from the study was that multi risk approaches do not consider the effects of climate change and mostly rely on the analysis of static vulnerability. The main challenge found was to the ability to develop a comprehensive list of indicators that would be dynamic to account for different climate induced hazards and risks.

**C] An index based methods to assess the risks of climate related hazards in coastal zones: The case of Tetouan (Satta et al, 2016)**

The study was conducted using regional coastal risk index for a coastal area in Mediterranean Morocco at a regional scale. The approach provides a useful tool for local coastal planning and management by exploring the effects and extensions of the climate related hazards and combining hazard, vulnerability and exposure variables in identify areas where the risk is likely to be relatively high. A panel of scientific experts and local policy makers were involved for assigned weights to each indicator to develop a coastal risk index. The experts were asked to assigned a score between 1 and 5 (5= high risk, 1= low risk) which described the relative contribution of each variable to represent the hazard, exposure and vulnerability. The results were presented on a GIS (geographical information system) platform. The study provided a set of maps that allowed identification of areas having higher risk from climate related hazards.

**D] Climate Change and Disaster Resilient Water, Sanitation and Hygiene Practices (WaterAid and NIRAPAD, December, 2012)**

This handbook focuses on the safe water supply, sanitation and hygiene practices for the rural areas and related problems and their solutions. It focuses on the basic concepts of the disaster risks in relation to climate change. Further, it discuss about the existing national policy structures and institutional systems for ensuring safe water, sanitation and hygiene practices as well the strategies to cope with the climate change disaster induced uncertainty. The strategies to manage climate change and disaster induced uncertainty are discussed below:

a) Use appropriate and effective technology to ensure water supply, sanitation services and hygiene practices in the changing circumstances. The current sources of water and the traditional sources of water and traditional technologies should be assessed to understand whether or to what extent they could serve their purposes.
b) Cost sharing through economic services- disaster risk and climate risk will increase the cost of safe water supply and sanitation services. I Therefore, economic pricing for the services should be introduced for the consumers to share a part of the cost.
c) Create demand through awareness as rising costs of the services may influence the demand for water at the household and personal levels negatively.
d) Subsidy for the poor and disadvantaged-it is understandable that the poor and disadvantaged households may find it difficult to bear the increasing cost of the services. Therefore, affordability should be carefully assessed in promoting new technologies. It is important to ensure that the economic pricing doesn't deprive the disadvantage and poor households.
e) Accountability and communities participation should be involved in both planning and implementation process. It should be built in at national level planning process.
f) Partnership among public, private and voluntary agencies-there has a need that the local Government bodies take part in supply and distribution to implement water supply and sanitation programme.

## *2.2 Vulnerability Indices*

| Study | Study Region | Vulnerability Index | Indicators | Methodology and Outcome |
|---|---|---|---|---|
| A] Multiple Use Water Services to Reduce Poverty and Vulnerability to Climate Variability and Change: A Collaborative Action Research Project in Maharashtra, India (IRAP, GSDA, and UNICEF, 2013) | Maharashtra | Multiple Use Water Systems (MUWS) Vulnerability Index | 20 parameters were identified and grouped under six sub-indices:<br>*A. Water Supply & Use* (Access to water supply source, Frequency of water supply, Ownership of alternative source "owned" , Access to other alternative source, Capacity of domestic storage systems, Quantity of water used, Quality of domestic water supplies, Total monthly water bill as a percentage of monthly income),<br>*B. Family Occupation & Social Profile* *(Family occupation*, Social Profile, Health expenditure),<br>*C. Social Institutions and Ingenuity* (Social institutions and Ingenuity),<br>*D.Climate & Drought Proneness* (Climate of the regions, Aridity and drought proneness),<br>*E. Condition of Water Resources* (Surface and groundwater availability in the area, Variability on resource conditions, Seasonal variation, Vulnerability of the resource to pollution or contamination) and<br>*F.Financial Stability* (financial Stability) | The developed MUWS Vulnerability Index is composed of six sub-indices which were identified based on expert knowledge and literature review. For computing the index, a survey was undertaken covering rural households in Maharashtra. The index has a maximum value of 10.0 representing lower vulnerability and minimum value of 0.0 representing higher vulnerability. |
| B] An index based methods to assess the risks of climate related hazards in coastal zones: The case of Tetouan (Satta et al, 2016) | Coastal zone of Tetouan Mediterranean Moroccan Coast | Multi-Scale Coastal Risk Index for Local Scale (CRI-LS) | 19 variables were categorized under three sub-indices:<br>*A. Coastal Hazards* (Sea level rise, storms, Mean annual max daily precipitation, Droughts, population growth, Tourism arrivals),<br>*B. Coastal Vulnerability* (Landforms, Coastal slope, Historical shoreline change, Elevation, distance from the shoreline, River flow regulation, Ecosystem health, Education level, Age of population, Coastal protection structures),<br>*C.Coastal Exposure* (Land cover, Population density) | A panel of scientific experts and local policy makers were involved for assigning weights to each identified indicator for developing a coastal risk index. The experts assigned a score between 1 and 5 (5= high risk, 1= low risk) which described the relative contribution of each variable to hazard, |

| Study | Study Region | Vulnerability Index | Indicators | Methodology and Outcome |
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| | | | | vulnerability and exposure. The index values were used to prepare maps for identification ofcoastal areas with relative higher risk from climate related hazards. |
| C] The Socio-Economic Vulnerability Index: A pragmatic approach for assessing climate change led risks-A case study in the south western coastal Bangladesh (Ahsan and Warener, 2014) | Seven unions of KoyraUpazilla, South-Western Coastal Bangladesh | Socio-Economic Vulnerability Index (SeVI) | 5 domains consisting of 27 indicators:<br>*A. Demographic* (Population density, Percentage of old and children in sample, Male-Female ratio in sample, etc.),<br>*B. Social* (Percentage of illiterate households in sample, Percentage of households not having brick built house in sample, etc.),<br>*C. Economic* (Percentage of households depends on natural source for their income (fisheries, agriculture etc.) in sample, Percentage of consumption expenditure on food in sample, etc.),<br>*D. Physical* (Percentage of households not getting electricity, Percentage of households not having sanitary latrine, Percentage of households using ponds, etc.),<br>*E. Exposure to Natural Hazards*(Percentage of households not willing to go cyclone shelter, Percentage of households not having shelter in cyclone shelter or with neighbours, etc.) | The SeVI wasdeveloped using five domains which include:physical, economic, social, demographic and exposure to natural hazards. Both primary and secondary data were used for development of the index. Indicators were identified based on the Focus Group Discussions (FGD) and through administering a questionnaire on 60 households from each region. The experts gave a relative weightage to each indicator, between 1 and 5 on the basis of importance of each indicator. |
| D] Climate Change and rural communities in Ghana: Social vulnerability, impacts, adaptations and policy implications. (Dumenu and Obeng, | Four ecological zones of Ghana | Social Vulnerability Index (SVI) | Six indicators has been used grouped under three domains:<br>*A. Demographic* (Household size, literacy),<br>*B. Economic* (Diversified sources of income, Climate sensitive occupation)<br>and<br>*C. Social* (Access to climate change information, Dependence on forest resources) | Authors used six demographic, social and economic indicators in assessing social vulnerability to climate change. Indicators were identified through expert judgment. Primary data was collected through questionnaire and interviews of 196 households in 14 rural communities. Qualitative and quantitative tools |

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| 2016) | | | | were used for data analysis. |
| E] Measuring household vulnerability to climate-induced stresses in pastoral rangelands in Kenya; implications for resilience programming (Opiyo et al, 2014) | Turkana County, North-Western rangelands of Kenya. | Household Vulnerability Index (HVI) matrix (Vulnerability= Adaptive capacity – (Sensitivity+Exposure) | 27 indicators have been identified under three major domains<br>*A. Social Vulnerability variables* (Sex of HH head: female headed, Age of HH head: 50+ years, Experiences in the area: less than five years, HH size: more than 5 persons etc.),<br>*B. Economic variables* (Non-firm income: HH with no firm income, Herd size in TLU: own less than 2 TLUs, Herd structure: no milking herd, Distance to Market: more than 10 km away, etc.),<br>*C. Environmental variables* (Climate change: experiencing change, Temperature: experiencing increase, Drought: noticed increasing events, Flood: notice change, etc.) | The study used various statistical and economic tools to measure vulnerability in the region. 27 socioeconomic and biophysical indicators were considered which were identified through questionnaire survey of 302 households. Principal Component Analysis (PCA) method was used for assigning weightage to each identifies indicator and compute HVI to classify households according to their level of vulnerability. |
| F] Climate Disaster Resilience of Dhaka City Corporation: An Empirical assessment at Zone Level (Parvin and Shaw, 2011) | Dhaka city, Bangladesh | Climate Disaster Resilience Index (CDRI) | The authors have identified 125 variables under 25 parameters in five main domains.<br>*A. Physical* (Electricity, Water, Sanitation and solid waste disposal, Accessibility to roads, Housing and Land use)<br>*B. Social* (Population, Health, Education and Awareness , Social Capital , Community preparedness during a disaster)<br>*C. Economic* (Income , Employment , Household assets , Finance and saving , Budget and subsidy ,<br>*D. Institutional* (Mainstreaming of DRR and CCA , Effectiveness of cities crisis management framework , Knowledge dissemination and management , Institutional collaboration with other organizations and stakeholders , during disasters , Good Governance<br>*E. Natural and related Parameters* (Intensity/severity of natural hazards ,Frequency of natural hazards , Ecosystem | Authors used Climate Disaster Resilience Index (CDRI) for analyzing risk for 10 zones of Bangladesh. The data was collectedby administering questionnaire on the planners involved in the preparation of the Detailed Area Plan (2009) in Dhaka city. |

| Study | Study Region | Vulnerability Index | Indicators | Methodology and Outcome |
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| | | | services , Land use in natural terms , Environmental policies | |
| G] Mapping Vulnerability to Climate Change (Heltberg and Osmolovskiy, 2010) | Tajikistan | Climate Change Vulnerability Index (CCVI = Adaptation + Exposure +Sensitivity /3) | Three determinants (Adaptive capacity, Sensitivity and Exposure) consists of 23 indicators<br>*A.Adaptive Capacity* (HH consumption per capita, Share of population with higher education, Negative Herfindahl index of income diversification, Share of HH having trust in people etc.),<br>*B. Sensitivity* (Negative of the amount of irrigated land per capita, Herfindahl index of agricultural land use diversification, share of HHs depending on agriculture, Share of population under age 5etc),<br>*C. Exposure* (Variability of average temperature in month, Variability of average precipitation in month, Range between maximum and minimum average temperature in month, Frequency of extremely hot months, when average temperature higher than $30^0$C, Frequency of extremely cold months etc.) | Authors mapped areas which are most vulnerable to the impacts of climate change and variability. They havederived vulnerability index as a function of the exposure to climate change variability and natural disasters; sensitive to impacts of that exposure and capacity to adapt to ongoing and future climate changes. The index can be used for decision making about adaptation responses that might benefit from an assessment of how and why vulnerability to climate change varies regionally. |
| H] Water and Poverty in Rural China: Developing an Instrument to assess Multi dimensions of Water and Poverty (Cohen and Sullivan, 2010) | Rural areas of China | Water, Economy, Investment and Learning Assessment Indicator (WEILAI) | 23sub-component identified under 9 components<br>*A. Water Resources* (Primary HH water source for HH use and limited HH agricultural use, etc.),<br>*B. Water Access* (Is water affordable if HH were required to pay, Distance travelled to collect water, Time needed to collect water etc.),<br>*C. Water resource management capacity* (Existence of a water user group in AV and awareness of it, HH's participation in any type of water management/use etc.),<br>*D. Sanitation* (Type of sanitation facilities, HH perceptions of their sanitation etc.),<br>*E. Education* (Children access to education, Student/teacher | The paper describes the theoretical developmental of a multidimensional, water-focused, thematic indicator of rural poverty. It is based on the identification of indicators, assigning weightage to indicators, methodology, field studies and statistical analysis. For the purpose, 534 households across 71 villages in China were surveyed. Principal Component Analysis was used for assigning weightage to each |

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| | | | ratio, Teachers level of training), *F. Health and Hygiene* (Access to healthcare, Affordability of healthcare etc.), *G. Food Security* (Area of arable land HH uses/had access to, HH is a net food consumer or exporter, etc.), *H. Environment* (Degree of erosion due to environmental deterioration, Secondary measures of deteriorating environment around HHs: insects etc.) | indicator. Based on the assigned weightage, the vulnerability index was developed. |
| I] Quantitative Assessment of Vulnerability to Flood Hazards in Downstream Area of Mono Basin, South-Eastern Togo: Yoto District (Kissi et al, 2015) | North-East Maritime Region, Yoto District | Flood Vulnerability Index (FVI) | 24 indicators identified in 3 sub domain: *A. Exposure* (Flood frequency, Flood Duration, Flood water level, Closeness to river body, Altitude), *B. Susceptibility* (percentage of Education: no schooling, Household size(more than 10%), Female headed, Farmers, Poor building material, HH with affected land, Community Awareness, HH coping mechanisms, Emergency services, HH past experience, HH preparedness), *C. Resilience* (Percentage of Warning systems, HH perception on flood risk, HH evacuation capability, HH flood training, Recovery capacity, Recovery time, Long term resident 10 year +, Environmental recovery) | Focus is on development of vulnerability framework and distinguishing three main components (exposure, susceptibility and resilience), to allow an in depth analysis and interpolation of indicators. For normalization, the actual data was transformed to a standardized score (between 0 and 1). |
| J] Identifying and Visualizing Resilience to Flooding via a Composite Flooding Disaster Resilience Index (Perfrement and Lloyd, nd) | 16 municipalities in the Greater Amsterdam | Flood Disaster Resilience Index (FDRI) | The FDRI has developed 11 indicators in four domains: *A. Social Environment* (Age, Transportation Access, Net Migration), *B. Built Environment* (Medical Capacity, Transportation network), *C. Natural Environment* (Runoff, Soil Permeability, Elevation (water level)), *D. Economic Environment* (Employment, Wealth, Economic damage for flood volumes) | Study developed a composite flooding disaster resilience index (FDRI) by aggregating individual resilience indicators under social, natural, built and economic categories. 16 municipalities across the Greater Amsterdam region were surveyed. The FDRI is a single figure summarizing a region's status on 11 indicators that influence the |

| Study | Study Region | Vulnerability Index | Indicators | Methodology and Outcome |
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| | | | | resilience of a region to natural hazards. A panel of 18 flood experts were asked to rate each indicator based on its correlation to the resilience level. Each indicator was ranked between 1 and 4. |

# 3 Developing an Index for Assessing Climate Risk in Water and Sanitation

For each component of risk, i.e. hazard, exposure and vulnerability,various factors influencing the climate related riskon rural water and sanitationwere identified and grouped under natural, physical, socio-economic and institutional factors. The factors and relevant variables were identified based on the literature review, expert knowledge and understanding of the study regions. Various factors and the way they can influence climate-induced hazard, and exposure and vulnerability of the communities to these hazards are discussed in the subsequent sub-sections and a summary of discussion is also presented in Table 1.

## 3.1 Factors Influencing Climate-Induced Hazard in WASH

Occurrence of hazards, droughts, floods and cyclone in this case, are mainly influenced by factors that are in natural domain. These include: rainfall and its variability; flood proneness; aridity; and overall renewable water availability. Above normal rainfall usually reduces the probability of occurrence of drought and helps in relieving water scarcity, and vice versa. As pointed out by Maliva & Missimer (2012), areas which receive low annual rainfall are at greater risk of having frequent droughts. In India, inter-annual variability in rainfall is found to be higher in regions of lower magnitude of (mean) annual rainfall (Pisharoty, 1990). Hence, such regions are likely to experience droughts more frequently as compared to those with lowervariability (Kumar et al, 2006 & 2008).

Further, given the nature of relationship between rainfall and runoff in semi-arid and arid tropics, the impact of meteorological droughts in terms of hydrological stress in areas experiencing low (mean) annual rainfall will be greater as compared to their counterparts receiving higher (mean) annual rainfall, for the same intensity of drought (in terms of SPI) (Source: based on Deshpande et al, 2016; James et al, 2015).

Flood prone areas are at a greater risk of getting floods resulting from excessively high rainfall (Brouwer et al, 2007).Heavy rainfalls there canhave adverse effect on quality of surface water and groundwater which cancontaminate water supply (Zimmerman et al, 2008; Brouwer et al, 2007).Another factor influencing water scarcity (during droughts) is the overall availability of annual renewable water in a region (Rijsberman, 2006). Renewable water availability of more than 1700 cum/capita/year is considered as secure (Falkenmark et al, 1989).

## 3.2 Factors Influencing Community'sExposure to Hazards

Community exposure to any hazard is influenced by several factors. Natural factors include: depth to water table; climate; and groundwater stock. Groundwater at shallow depth will be susceptible to biological contamination during floods. Nevertheless, high groundwater stock can play a vital role in buffering the effects of the risks posed duringdroughts (Calow et al, 2010). Further, in areas with cold climate, exposure of community to the risk posed during a bad rainfall year will be low as overall water requirements itself will be less (Kabir et al, 2016a, 2016b). Whereas, areas with humid climate have a greater chance of outbreak of water borne diseases during floods (Githeko et al, 2016).

There are several physical factors influencing community exposure to hazards and they include: characteristics of the water source; age of the water supply system; provision of buffer storage of water in reservoirs per capita; proportion of HHs covered by tap water supply; proportion of HHs having access to modern toilets; flood control measures such as dams; and water pumping facilities. A perennial water source wouldsignificantly reduce community exposure to droughts. Further, anageing water supply system is at a greater risk of damage and disruption in working during natural calamities such as floods and cyclones. Adequate provision of buffer water storage in the reservoirs is one other important factor which can reduce exposure to water scarcity conditions during droughts (Kumar, 2010, 2016; McCartney & Smakhtin, 2010). Similarly, households' access to tap water supply and modern toilets will help in counteracting prolonged exposure to climate induced risks (Hunter et al, 2010; Montgomery & Elimelech, 2007; WHO, 2002). Further, flood control measures such as embankments, dykes, dams and water pumping infrastructure will help in reducing severity of floods.

Socio-economic factors include: proportion of people living in low-lying areas; and proportion of people having access to water supply source within the dwelling premise. Low lying areas, due to its topographical disadvantage, will be more prone to floods (Patz and Kovats, 2002). Nevertheless, people having access to water supply within their premises will have less exposure to risk posed by droughts or floods, owing to the fact that there will be lesser chances of contamination of water that normally happens during collection, conveyance and storage, if the source is available (WHO, 2002). Also, people who follow good hygiene will also be less exposed to risks such as food contamination.

Institutional and policy factors also play an important role in regulating community exposure to climate induced risks. Policy to hire private tankers for emergency water supply in rural areas and number of such tankers being made available will help community to face water stress induced by droughts. Further, provision of disaster risk reduction measures such as flood and cyclone warning, drought prediction, and evacuation measures will help community to prepare better for any adverse eventuality (Pollner et al, 2010).

## 3.3 Factors Influencing Community Vulnerability to Hazards

These factors are mainly natural, socio-economic and institutional in nature. Climate is the single most important natural factor influencing the community vulnerability to hazard. For instance, cold climate and humidity increases flood related health risks caused by bacteriological contamination of waterand food such as diarrhoeadue to the prevalence of water related insect vectors and pathogens in the environment (Haines et al, 2006; Githeko et al, 2016).Inadequate personal and community and hygiene resulting from water shortages can result in diseases such as diarrhoea (Esrey *et al*, 1985; Howard, 2005). But, in hot and arid and semi-arid climates, breeding of water-related insect vectors that can cause such diseaseswould be less during hot weather conditions (Hunter, 2003) and therefore the health risks such as diarrhoea. Hot and arid areas are more prone to drought related health risks such as dehydration (Haines et al, 2006).

Population density is a key socio-economic variable affecting vulnerability of communities to the health risks associated with climate related hazards as more densely populated areas have greater faecal loadings within the environment and these are associated with greater vulnerability to infectious disease (Woodward et al, 2000).

The burden of waterborne disease is often closely linked to poverty (Fass, 1993; Stephens et al, 1997) and malnutrition. The poor tend to be more vulnerable to disease and have least access to basic services(WHO & UNICEF, 2000).This could be because high proportion of people living under poverty lack the wherewithal to have access to alternate sources of water including purchased water, and are also unhealthy (prevalence of undernourishmentin general and malnourishment among children). Nevertheless, better access to primary health services will make them less vulnerable. People with malnutrition are more vulnerable to water borne diseases.

Institutional and policy factors such as ability to provide relief and rehabilitation measures to people affected during floods and cyclones (in terms of no. of agencies, including government, private and NGOs) improve community adaptive capacity against climate induced vulnerabilities. Similarly, presence of adequate number of public health infrastructure decreasespopulation vulnerabilityto the severity of diseases caused during hazards (Haines et al, 2006). Finally, social ingenuity also matters when it comes to the question of adapting to natural disasters and reducing the vulnerability. Social cohesion, which is characteristic of homogeneous communities, also helps in adaptation and vulnerability reduction (IRAP, GSDA & UNICEF, 2013).

Table 1: Identified factors influencing climate induced risk in rural water and sanitation

| S. No | Sub-Indices (Factor) | Variable (Indicators) | Rationale | Impact on severity of Risk (Negative or Positive) |
|---|---|---|---|---|
| **A** | **Hazard Sub-index** | | | |
| 1 | Natural | Rainfall | In high rainfall areas, the drought impacts on hydrology will be less as compared to low rainfall areas and vice versa in low rainfall areas. | Negative<br>Positive |
| | | Rainfall variability | In areas of high rainfall variability, the frequency of occurrence of severe droughts will be higher | |
| | | Flood proneness | 'Flood prone' areas are more susceptible to hazards associated with high rainfall | Positive |
| | | Aridity | Impacts of droughts in areas having high aridity in terms of hydrological changes will be more as compared to areas of low aridity | Positive |
| | | Annual Renewable Water Availability | Renewable water availability of more than 1700 cum/capita/year is considered as secure | Negative |
| **B** | **Exposure Sub-Index** | | | |
| 1 | Natural | Depth to ground water table | Groundwater at shallow depth will be susceptible to biological contamination during floods | Negative |
| | | Temperature and Humidity | In areas with cold and humid climate, there is high chance of water & food contamination due to unhygienic conditions and spreading of insect vectors | Positive |
| | | Groundwater stock | Act as buffer during droughts; normally available in the alluvial areas and as valley fills along rivers | Negative |
| 2 | Physical | Characteristics of water resources | Perennial water source would significantly reduce community exposure to droughts | Negative |
| | | Condition of the water supply system | Old water supply systems are more susceptible to disruption | Negative |

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| | | | and damage during floods and cyclones | |
| | | Provision of buffer storage of water in reservoirs per capita | Reduces exposure to water scarcity conditions during droughts | Negative |
| | | Proportion of HHs covered by tap water supply | Reduces the chances of contamination of water during collection & storage | Negative |
| | | Proportion of HHs having access to modern toilets | Reduces the chances of vector borne diseases through food contamination etc. | Negative |
| | | Flood control measures such as embankments, dykes, dams and water pumping facilities | Reduce severity of floods | Negative |
| 3 | Socio-Economic | Proportion of people living in low-lying areas | Relatively more exposed to flood hazards | Positive |
| | | Proportion of people having access to water supply source within the dwelling premise | Less exposure to risk posed by droughts or floods | Negative |
| | | Hand washing before and after food and after toilet use | Hand washing before and after food and after toilet use will help reduce the chances of contamination of food with faecal matter. | Negative |
| 4 | Institutional & Policy | Existence of policy to hire private tankers for emergency water supply | Help community to face water stress induced by droughts | Negative |
| | | Provision for tanker water supply in rural areas in terms of no. of tankers | Increases the community's ability to tide over the crisis caused by reduced water supply from the public systems | Negative |
| | | Disaster risk reduction measures available | Help community to prepare better for any adverse eventuality | Negative |
| **C** | **Vulnerability Sub-Index** | | | |
| 1 | Natural | Climate | In cold and humid areas, communities will be more prone to flood and water scarcity related health risks | Positive |
| | | | In hot and arid areas, communities are more prone to heat stroke, dehydration | Positive |
| 2 | Socio-Economic | Population density | High population density increases vulnerability | Positive |
| | | Proportion of people living under poverty | Vulnerability will be high for those who lack wherewithal to have access to alternate sources | Positive |

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| | | | of water including purchased water | |
| | | Proportion of people who are unhealthy | Undernourished people and malnourishment especially among children make community more vulnerable | Positive |
| | | Access to primary health services | Better access make community less vulnerable | Negative |
| | | Percentage of children under the age of 5 with stunting (Height-for-age) | Physical growth of children (under the age 5), an indicator of the nutritional well-being of the population, influences vulnerability to diseases | Negative |
| 3 | Institutional & Policy | Ability to provide relief and rehabilitation measures for floods and cyclones (no. of agencies, including government, private and NGOs) | Improve community adaptive capacity | Negative |
| | | Social ingenuity and cohesion | Improves community adaptive capacity | Negative |
| | | Adequate no. of primary and other health infrastructure | Decreasescommunityvulnerability to diseases | Negative |

The matrix in Table 2 suggests the quantitative criteria for assigning values to various sub-indices for computing the climate risk index for different types of areas.

## Table 2: Matrix for Computing the Values of Various Indices for Assessing the Climate-Induced Risk in Water and Sanitation in Maharashtra

| **Sub-Index (Factors)** | **Variable (Indicators)** | **Impact on severity of Risk (Negative or Positive)** | **Score** | | | **Score given** | **Remarks** |
|---|---|---|---|---|---|---|---|
| | | | **1 = Low** | **2 = Moderate** | **3 = High** | | |
| A. Hazard Sub-Index | | | | | | | |
| Natural | Rainfall | Negative | Average annual rainfall greater than or equal to 1000 mm | Average annual rainfall between 500-1000 mm. | Average annual rainfall less than equal to 500 mm. | | The hazard is drought |
| | Rainfall Variability | Positive | Coefficient of variation in rainfall is less than 17% | Coefficient of variation in rainfall is equal to/between 17 and 40% | Coefficient of variation in rainfall is greater than 40% | | As per guidelines of IMD |
| | Flood Proneness | Positive | Probability of occurrence of flood less than 10% | Probability of occurrence of flood is between 10-33% | Probability of occurrence of flood more than 33% | | |
| | Aridity | Positive | Humid-sub-humid | Semi-arid | Arid to Hyper-arid | | As per guidelines of IMD |
| | Annual Renewable Water Availability | Negative | Renewable water availability of more than equal to 1700 | Renewable water availability of between 1000-1700 | Renewable water availability of less than equal to 1000 cum/capita/year | | |

| Sub-Index (Factors) | Variable (Indicators) | Impact on severity of Risk (Negative or Positive) | Score | | | Score given | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 1 = Low | 2 = Moderate | 3 = High | | |
| | | | cum/capita/year | cum/capita/year | | | |
| B. Exposure Sub-Index | | | | | | | |
| Natural | Depth to ground water table | Negative | Depth to ground water table is greater than equal to 30 m | Depth to ground water table is between to 5-30 m | Depth to ground water table is less than equal to 5 m | | |
| | Temperature and Humidity | Positive | Temperature ranging between 30-35$^0$C and Humidity ranging 30±5% to 50±3% . | Temperature ranging between 27-30$^0$C and Humidity ranging 30±5% to 50±3% | Temperature ranging between 23-27$^0$C and Humidity ranging 60±8% to 80±6% most favorable condition for unhygienic conditions | | |
| | Groundwater stock | Negative | Groundwater stock is 5 times more than annual recharge | Groundwater Stock is 2 times more than the annual recharge | Groundwater stock is equal to or less than the annual recharge | | As per guidelines of CGWB |
| Physical | Characteristics of natural water resources | Negative | Perennial Water source with low inter-annual variability | Perennial source with high inter-annual variability | Seasonal water sources (ephemeral rivers, lakes, ponds etc,) | | |

| Sub-Index (Factors) | Variable (Indicators) | Impact on severity of Risk (Negative or Positive) | Score | | | Score given | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 1 = Low | 2 = Moderate | 3 = High | | |
| | | | (Example. river) | | | | |
| | Condition of the water supply system | Negative | New water supply pipeline systems (Less than 5 years) | Medium aged water supply pipeline systems (between 5-15 years ) | Old aged water supply pipelines systems ( more than 15 years) | | |
| | Provision of buffer storage of water in reservoirs per capita | Negative | Provision of buffer storage in a reservoir minimum 36 $m^3$/capita/year | Provision of buffer storage in a reservoir between 15 $m^3$ /capita/year | Provision of buffer storage in a reservoir less than 9 $m^3$ /capita/year | | |
| | Proportion of HHs covered by tap water supply | Negative | More than 75% of HHs are covered by tap water supply | 40-60% of HHs are covered by tap water supply | Less than equal to 40% of HHs are covered by tap water supply | | |
| | Proportion of HHs having access to modern toilets | Negative | More than 80% of HHs having access to modern toilets and usage is more than 90% | 30-80% of HHs having access to modern toilets and usage is between 45-90% | Less than equal to 30% of HHs having access to modern toilets and usage is more than 45% | | |
| | Flood control measures such as embankments, dykes, dams and water pumping | Negative | Flood control measures available | | No Flood control measures available | | |

| Sub-Index (Factors) | Variable (Indicators) | Impact on severity of Risk (Negative or Positive) | Score | | | Score given | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 1 = Low | 2 = Moderate | 3 = High | | |
| | facilities | | | | | | |
| Socio-Economic | Proportion of people living in low-lying areas | Positive | Less than equal to 25% of people living in low-lying areas | 25-50% of people living in low-lying areas | Greater than equal to 50% of people living in low-lying areas | | |
| | Proportion of people having access to water supply source within the dwelling premise | Negative | More than 75% of people Access to water supply source within the dwelling premise | 40-75% of people having Access to water supply source within the dwelling premise | Less than 25% of people having Access to water supply source within the dwelling premise | | |
| | Hand-washing before and after food and after toilet use | Negative | Hand-washing before and after food and after toilet use | Hand-washing after toilet use | Hand washing after food/no hand washing | | |
| Institutional & Policy | Existence of policy to hire private tankers for emergency water supply | Negative | Policy exist to hire private tankers for emergency water supply | | No Policy exist to hire private tankers for emergency water supply | | |
| | Provision for tanker water supply in rural areas in terms of no. of tankers | Negative | More than 1 tanker for 20 HHs | 1 tanker for 20-50 HHs | Less than one tanker for 50 HHs | | 1 tanker capacity of 7000 liters meet requirement of 20 HHs (70 |

| Sub-Index (Factors) | Variable (Indicators) | Impact on severity of Risk (Negative or Positive) | Score | | | Score given | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 1 = Low | 2 = Moderate | 3 = High | | |
| | | | | | | | liters/capita/day) |
| | Disaster risk reduction measures available | Negative | Disaster risk reduction force available within a radius of 100 km | Disaster reduction force available within a radius of 100-500 km radius | Disaster risk reduction force available outside 500 km radius | | |
| C. Vulnerability Sub-Index | | | | | | | |
| Natural | Climate | Positive | Temperature ranging between 30-35$^0$C and Humidity ranging 30±5% to 50±3% ./ Mean annual temperature less than 33$^0$C and humidity above 90% | Temperature ranging between 27-30$^0$C and Humidity ranging 30±5% to 50±3% / Mean annual temperature between 33-40$^0$C and Humidity between 50-65% | Temperature ranging between 23-27$^0$C and Humidity ranging 60±8% to 80±6% / Temperature less than 40-46$^0$C and Humidity less than 50% | | |
| Socio-Economic | Population density | Positive | Pop. Density less than 200 persons/sq. km | Pop. Density in the range of 200-500 person/sq. km | More than 500 persons/sq. km | | |

| Sub-Index (Factors) | Variable (Indicators) | Impact on severity of Risk (Negative or Positive) | Score | | | Score given | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 1 = Low | 2 = Moderate | 3 = High | | |
| | Proportion of people living under poverty | Positive | Less than equal to 25% of people living under poverty | 25-80% of people living under poverty | Greater than 60% of people living under poverty | | |
| | Proportion of people who are unhealthy | Positive | Infant mortality rate less than equal to 12.0 (per 1,000 people) | Infant mortality rate between 12.0 to 60.0 (per 1,000 people) | Infant Mortality rate greater than 60.0 (per 1,000 people) | | |
| | Access to primary health services | Negative | More than 60% people having access to primary health services | 25-60% of people having access to primary health services | Less than 25% of people having access to primary health services | | |
| | Percentage of children under the age of 5 with stunting (low height-for-age ratio) | Negative | Average height of children below the age of 5 as a % of the median is 95 to 110 | Average height of children below the age of 5 as a % of the median is 85 to 89 | Average height of children below the age of 5 as a % of the median is less than 85 | | For the median, we would consider the state as a whole |
| Institutional & Policy | Ability to provide relief and rehabilitation measures for floods and cyclones (no. of | Negative | More than 1 NGO for 1,000 people | One NGO for 1,000-2,000 people | Less than one NGO for 2,000 people | | As per NGO regulations one NGO covered 600 peoples |

| Sub-Index (Factors) | Variable (Indicators) | Impact on severity of Risk (Negative or Positive) | Score | | | Score given | Remarks |
|---|---|---|---|---|---|---|---|
| | | | 1 = Low | 2 = Moderate | 3 = High | | |
| | agencies, including government, private and NGOs) | | | | | | |
| | Social ingenuity and cohesion | Negative | Settled, but heterogeneous communities not exposed to natural disasters | Settled, but heterogeneous communities exposed to natural disasters | Settled and homogenous communities, exposed to natural disasters | | |
| | Adequate no. of primary and other health infrastructure | Negative | One Sub Health Centre covered 3,000 to 5,000 of rural population | One Sub Health Centre covered 6,000 to 8,000 of rural population | One Sub Health Centre covered more than 8,000 of rural population | | As per Ministry of FHW guidelines one Sub-centre (health centre covered 3,000-5,000 rural population |

# 4 Computation of the Composite Climate Risk Index

Value obtained or estimated for each indicator will be normalized using a scale ranging from 1 to 3. Maximum score 3 will be assigned to the highest risk variable in terms of its relative contribution to generate risk and the minimum score 1 will be assigned to the lowest risk variable.The sum of weights within each sub-index must be equal to 1 or 100%.

For obtaining numerical value of each sub-index, product of score and weightage for each indicator will be added. It can be represented as:

$$Sub - Indices = \frac{\sum_{i=0}^{n} S_i}{Max - Score\ of\ the\ Component}$$

Where, S is the product of score and weightage obtained by each variable under the sub-index and$n$ is the total number of variable under each sub-index.

The composite risk index for water and sanitation ($R_i$-WASH) will be computed by multiplying the three sub-index values which include hazard ($H_{WASH-SI}$), exposure ($E_{WASH-SI}$) and vulnerability ($V_{WASH-SI}$). It can be represented as:

$$R_i - WASH = H_{WASH-Si} \times E_{WASH-Si} \times V_{WASH-Si}$$

## References


Ahsan Md. N,& Warner, J. (2014). The socio-economic vulnerability index: A pragmatic approach for assessing climate change led risks-A case study in the south-western coastal Bangladesh. *International Journal of Disaster Risk Reduction, Elsevier* 8, 32-49.

Brouwer, R., Akter, S., Brander, L., &Haque, E. (2007). Socioeconomic vulnerability and adaptation to environmental risk: a case study of climate change and flooding in Bangladesh. *Risk Analysis*, *27*(2), 313-326.

Calow, R. C., MacDonald, A. M., Nicol, A. L., & Robins, N. S. (2010). Ground water security and drought in Africa: linking availability, access, and demand. *Ground Water*, *48*(2), 246-256.

Cohen A and Sullivan C A. (2010) Water and poverty in rural China: Developing an instrument to assess the multiple dimensions of water and poverty.*Ecological Economics, Elsevier*, 69, 999-1009.

Deshpande, S., Bassi, N., Kumar, M. D., &Kabir, Y.(2016). Reducing vulnerability to climate variability: Forecasting droughts in Vidarbha region of Maharashtra, western India. In *Rural water systems for multiple uses and livelihood security* (pp. 49-68). Elsevier, Netherlands.

Dumenu W. K. and Obeng E. A. (2016) Climate change and rural communities in Ghana: Social vulnerability, impacts, adaptations and policy implications, *Environmental Science & Policy,* 55, 208-217.

Falkenmark, M., Lundqvist, J., &Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches. *Natural Resources Forum, 13*(4), 258-267.

Fass, S. M. (1993). Water and poverty: implications for water planning.*Water Resource Research*, *29*(7), 1975–1981.

Gallina V, Torresan S, Critto A, Sperotto A, Glade T and Macromini A. (2016) A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. *Journal of Environmental Management. Elsevier,* 168, 123-132.

Githeko, A. K., Lindsay, S. W., Confalonieri, U. E., & Patz, J. A. (2000). Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization*, *78*(9), 1136-1147.

Heltberg R and Osmolovskiy M. B. (December, 2010) Mapping Vulnerability to Climate Change. The World Bank, 1-19.

Hunter, P. R., MacDonald, A. M., & Carter, R. C. (2010).Water supply and health. *PLoS Med*, *7*(11), e1000361.

IPCC (2007). Climate change 2007, climate change impacts, adaptation and vulnerability. Working Group II contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Summary for policymakers, 23

IRAP, GSDA and UNICEF. (2013) *Multiple-Use water services to reduce poverty and vulnerability to climate variability and change-A collaborative action research project in Maharashtra, India* . Final Report Submitted to UNICEF Field office, Mumbai.

James, A.J., Kumar, M.D., Batchelor, J., Batchelor, C., Bassi, N., Choudhary, N., Gandhi, D.,Syme, G., Milne, G., & Kumar, P. (2015).*Catchment assessment and management planning for watershed management*.World Bank, Washington DC.

Kabir, Y., V. Niranjan, V., Bassi, N., & Kumar, M. D. (2016a). Multiple water needs of rural households: Studies from three agro-ecologies in Maharashtra. In *Rural water systems for multiple uses and livelihood security* (pp. 49-68). Elsevier, Netherlands.

Kabir, Y., Bassi, N., Kumar, M. D., & Niranjan, V. (2016b).Multiple-Use water systems for reducing household vulnerability to water supply problems. In *Rural water systems for multiple uses and livelihood security* (pp. 69-78). Elsevier, Netherlands.

Kissi, A. E., Abbey, G. A., Agboka, K., &Egbendewe, A. (2015). Quantitative Assessment of Vulnerability to Flood Hazards in Downstream Area of Mono Basin, South-Eastern Togo: Yoto District. *Journal of Geographic Information System*, *7*(06), 607.

Kumar, M. D. (2010). *Managing water in river basins: hydrology, economics and institutions*. OUP, New Delhi.

Kumar, M. D., Ghosh, S., Patel, A., Singh, O. P., & Ravindranath, R. (2006). Rainwater harvesting in India: some critical issues for basin planning and research. *Land Use and Water Resources Research*, *6*(1), 1-17.

Kumar, M. D., Patel, A., Ravindranath, R., & Singh, O. P. (2008).Chasing a mirage: water harvesting and artificial recharge in naturally water-scarce regions. *Economic and Political weekly*, *43*(35), 61-71.

Kumar, M. D., Saleth, R. M., Foster, J. D., Niranjan, V., & Sivamohan, M. V. K. (2016). Water, human development, inclusive growth, and poverty alleviation: International perspectives. In *Rural water systems for multiple uses and livelihood security* (pp. 17–47). Elsevier, Netherlands.

Maliva, R., & Missimer, T. (2012).Aridity and drought. In *Arid lands water evaluation and management* (pp. 21-39). Springer, Berlin, Heidelberg.

McCartney, M., & Smakhtin, V. (2010). *Water storage in an era of climate change: addressing the challenge of increasing rainfall variability. Blue paper*(No. 212430). International Water Management Institute.

Montgomery, M. A., & Elimelech, M. (2007). Water and sanitation in developing countries: including health in the equation. *Environmental Science & Technology*, *41*(1), 17-24.

Opiyo EO F, Wasonga O V and Nyangito M M. (2014) Measuring household vulnerability to climate-induced stresses in pastoral rangelands of Kenya: Implications for resilience programme.*Pastrolism: Research, Policy and Practice*, 4(10), 1-15.

Parvin G A, Shaw R. (2011). Climate disaster resilience of Dhaka city corporation: An empirical assessment at zone level. *Risk, Hazards & Crisis in Public Policy*, 2(2), 1-30.

Patz, J. A., & Kovats, R. S. (2002).Hotspots in climate change and human health. *British Medical Journal*, *325*(7372), 1094.

Perfrement T & Lloyd T. (nd). Identifying and visualizing resilience to flooding via a composite Flooding Disaster Resilience Index..University of New South Wales, Sydney.

Pollner, J., Kryspin-Watson, J., &Nieuwejaar, S. (2010). *Disaster risk management and climate change adaptation in Europe and central Asia*. Washington DC: World Bank.

Rijsberman, F. R. (2006). Water scarcity: fact or fiction?. *Agricultural water management*, *80*(1), 5-22.

Satta A, Snoussi M, Puddu M, Flayou L and Hout R. (2016). An indexed based method to assess the risks of climate related hazards in coastal zones: The case of Tetouan. *Estuarine, Coastal and Shelf Sciences, Elsevier*. 175, 93-105.

Sisto N P, Ramirez A I, Aguilar-Barajas I., &Magana-Rueda V. (2016). Climate threats, water supply vulnerability, and the risk of a water crisis in the Monterrey Metropolitan Area (Northeastern Mexico). *Physics and Chemistry on the Earth, Elsevier*, 91, 2-9.

Stephens, C., Akerman, M., Avle, S., Maia, P. B., Campanario, P., Doe, B., &Tetteh, D. (1997). Urban equity and urban health: using existing data to understand inequalities in health and environment in Accra, Ghana and Sao Paulo, Brazil. *Environment and Urbanization*, *9*(1), 181-202.

Sullivan, C. (2002).Calculating water poverty index.*World Development*, *30*(7), 1195-1211

UNICEF (2016) Sanitation Contexts and Considerations for Risk Informed Programming and Climate Resilient Development, February 8-9, 2016.

UNICEF and GWP (2014) WASH Climate Resilient Development: A Strategic Framework, UNICEF and Global Water Partnership, ISBN: 978-91-87823-08-4.

WaterAid & NIRAPAD. (December, 2012) Handbook: Climate change, and disaster resilient water, sanitation and hygiene practices. Bangladesh, 1-64.

Woodward, A., Hales, S., Litidamu, N., Phillips, D., & Martin, J. (2000).Protecting human health in a changing world: the role of social and economic development. *Bulletin of the World Health Organization*, *78*(9), 1148-1155.

World Health Organization (WHO). (2002). *Managing water in the home: accelerated health gains from improved water supply.* WHO, Geneva.

World Health Organization (WHO) & United Nations Children's Fund (UNICEF).(2000).*Global water supply and sanitation assessment 2000 report*.World Health Organization/United Nations Children's Fund, Geneva/New York.

Zimmerman, J. B., Mihelcic, J. R., & Smith, A. J. (2008).Global stressors on water quality and quantity. *Environmental science & technology*, *42*(12), 4247-4254.