An assessment of vulnerability to water-energy nexus for Indian states

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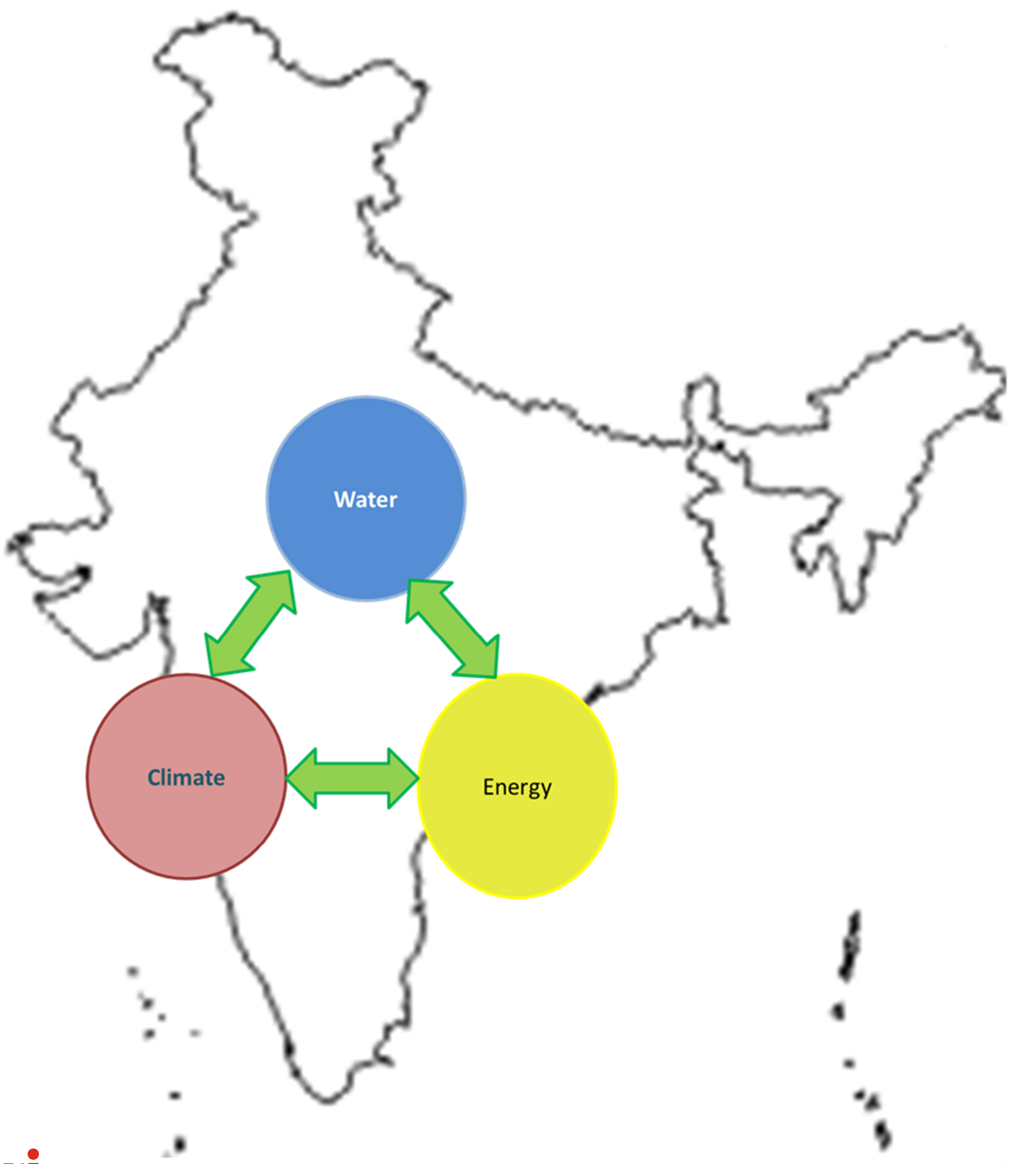

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1.0 Introduction

Water and energy are deeply intertwined. Energy production requires a reliable, abundant, and predictable source of water. Similarly, supply of water requires energy, mainly for pumping of water, its extraction and purification. This connect is often missed and hence the nations thrive individually for water and energy security, whereas the nexus starkly suggests the need of integrated efforts. The drivers like population increase, rapid urbanization, and development, are increasing the demand for both the resources, while supply is constrained by limited resource availability, high associated costs, and the impacts of climate change. These issues, influencing water and energy together, make up the "climate change-water-energy nexus."

India is a diverse country with various agro-climatic zones spread across length and breadth of its area. It receives uneven distribution of rainfall both temporally and spatially and hence the availability of water resources in all the states is variable. In terms of demand also, each state has different dynamics, and the demand is majorly driven by agricultural patterns, total population and industrialization in the states. Similarly, states have different installed capacity of thermal power generation, which compete with other sectors for available water resources. Thus, implications of climate change-water-energy nexus are likely to differ among various states. Therefore, this study aims to make a quantitative assessment of climate change-water-energy (CCWE) nexus, to evaluate the states for stress on water resources from different sectors, and their competition with water demand for energy production in the states.

2.0 Identifying the sectoral linkages

Energy for Water

Water is consumed across different sectors viz., agriculture, industries, domestic, commercial and power sectors, to varying degrees. For example, agriculture sector accounts for almost 85% of the total water consumed in the country. For irrigated crop production, water is either extracted from groundwater sources or is channelized from surface water sources. Both these processes of access to irrigation water are energy dependent. According to the statistics of Government of India, doubling the total food grain production since 1980-81, to offset the increase in population and maintain the per capita per day net food grain availability constant, has been at the cost of five times increase in electricity consumption for agriculture purposes.

Similarly, domestic sector consume water either extracted from underground aquifers through bore wells or supplied by municipal bodies through booster pumps. In both cases, water is pumped and consumes energy. Factors like population of a city, distance from the water source, length of pipelines, depth of aquifer etc., affect the quantum of energy consumed for water provisioning. With increasing population density in urban areas and growth of multi-storied residential flats, energy dependence of water supply to domestic consumers is likely to increase further.

Industries like textile, leather, steel and cement etc. are known to be water guzzlers, consuming significant amount of water during manufacturing processes. Water is required either as direct input or for cleaning, washing, bleaching etc. This water is supplied through mix of borewells and municipal supply, which again consumes energy for pumping water.

Water for Energy

Water is used in both the production of energy resource as well as in production of electricity from these resources. Water use is a major component in coal mining and petroleum refining. Besides hydropower, thermal and nuclear power plants use water as coolant for their boilers. In India, production of coal has increased by 7.5 times and production of electricity has increased by 13 times since 1970-71[1]. For a typical 500 MW coal fired unit, the amount of cooling water required for condenser and auxiliary cooling is about 60,000 m^3/h.[2] Thus, India with an installed capacity of 131200 MW of thermal power plants requires 12.6 million m^3 water per hour for electricity production at 80% load factor. This is equivalent to per capita per day water requirement of 10% population of the country.

Climate change and Water-Energy Nexus

Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems[3]. Simultaneously, climate change is likely to influence the energy production as well as demand. Specifically, climate change will lead to increase in energy used to supply other resources for climate-sensitive processes, such as pumping water for irrigated agriculture and municipal uses[4]. Moreover, increase in temperatures are likely to cause an increase in cooling loads and irrigation demands due to increased water needs, and the need to extract water from greater depths. While climate change impacts availability of water, this in turn will increase the stress on energy production by limiting the availability of water for energy production processes. Thus, climate change has its influence on water and energy both, as well as on linkages existing between the two.

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[1] Energy Statistics, 2012

[2] Central Electricity Authority, 2012

[3] Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

[4] Scott, M. J. and Y. J. Huang, 2007: Effects of climate change on energy use in the United States in Effects of Climate Change on Energy Production and Use in the United States. A Report by the U.S. Climate Change Science Program and the subcommittee on Global Change Research. Washington, DC.

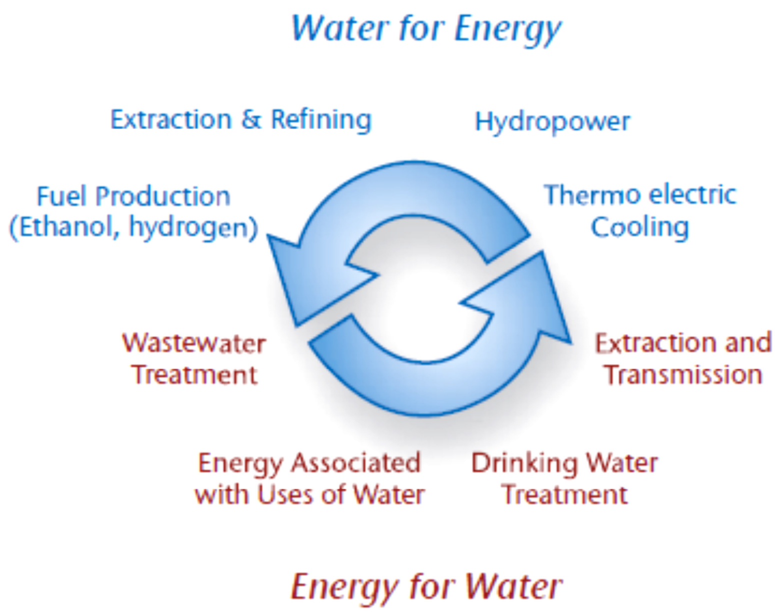

***Figure 1: Water-Energy Linkages** (source Paul Reiter/ International Water Association)*

3.0 Approach and Methodology

To understand the vulnerability due to interdependence of water and energy, it is necessary to quantify the interlinkage, and assess the competition in demand of water for agriculture, industrial production and domestic consumption, and demand from electricity production. This study is an attempt to make quantitative estimation of vulnerability to water-energy (WE) nexus at the state level in India. This has been done by developing a quantitative score matrix, referred as 'WE Vulnerability Index' for all the states of India. Evaluation using such an index has helped to understand the implications of multiple regulators on each other's and on overall WE scenario in Indian states. The construction of an index involves the selection of relevant indicators which are aggregated. Approach adopted was dependent on integration of core aspects of WE nexus. Each of these core aspects is driven by set of indicators which were assessed and ranked to establish the vulnerability index (Figure 2).

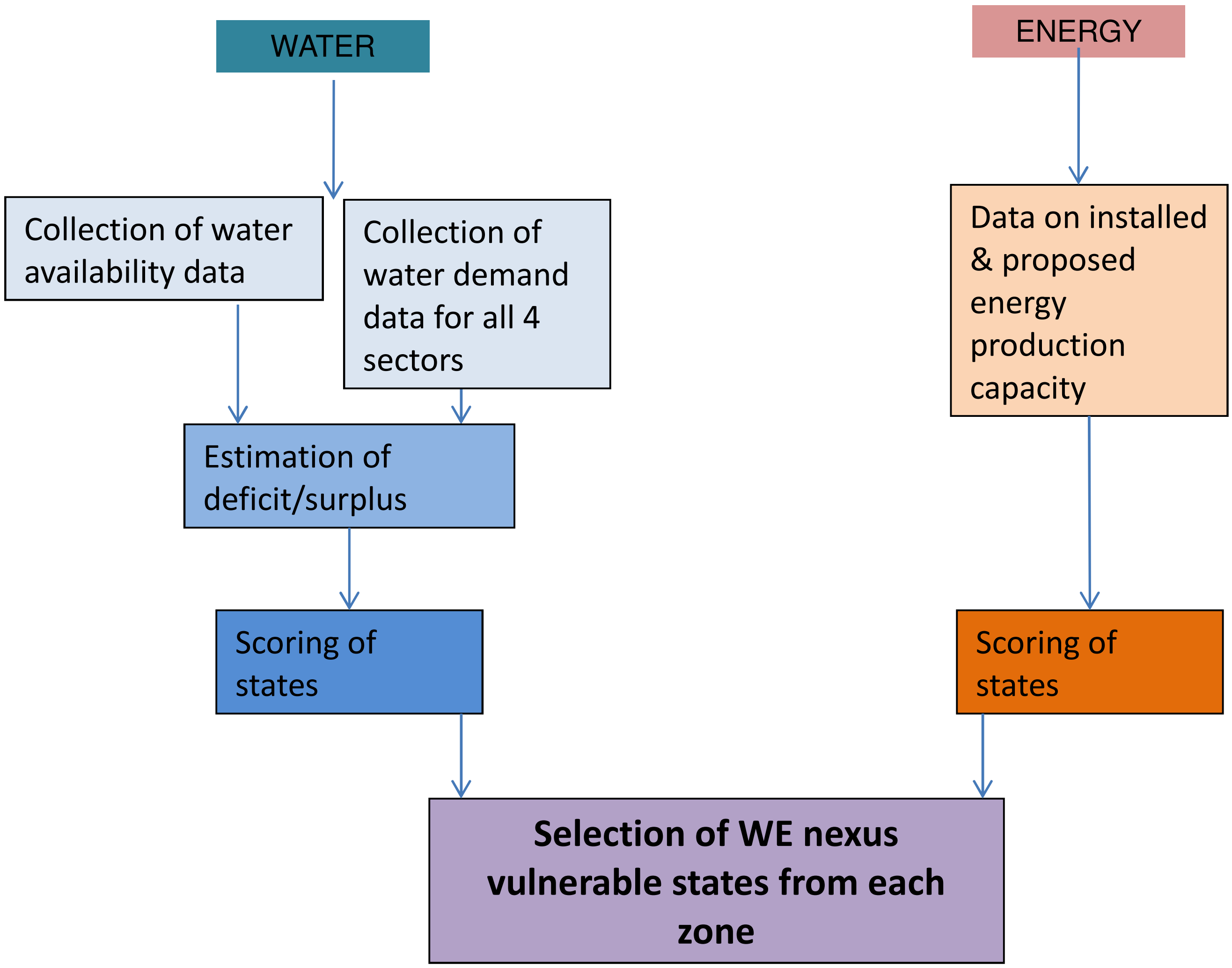

Figure 2: Integrated approach adopted for state selection

3.1 Nexus Indicators

Availability of water plays an important role to establish the vulnerability of the nexus. Based on the present water availability and demand from all the dependent sectors, net surplus or deficit for each of the state was estimated. Based on this estimation, scoring was done as 1 for the most surplus states and 5 for the most deficient state. Based on this scoring, vulnerability was assessed at one step forward to pinpoint the distressed states.

For water demand, indicators used as part of vulnerability assessment were linked to four important water use sectors - domestic, industrial, energy and agriculture. For each of these four sectors, certain criterions were taken to assess and evaluate the indicators. For supply side, water availability in state was taken for understanding the surplus or deficit situation in each state.

For assessment of water intensity of agriculture in states, three crops with largest acreage in the state, and simultaneously being water intensive were selected. Rice and Sugarcane are the two most water intensive crops, grown invariably in all the major states of India. Wheat or Cotton was selected as the third crop, based on their production in individual states. Along with water consumption of major crops, production of horticultural crops as well as production of animal husbandry products- milk, meat and egg, was considered.

Similarly, production capacity of major water intensive industries was considered to understand the requirement of water and consequential implications on energy for water. Industries considered for the study were Iron and Steel, Fertilizer, Paper and Pulp and Textile, and state-wise installed capacity of production was taken as metrics for their dependence on water availability.

For the analysis of water demand for domestic consumption, the study incorporated total population of the states, total urban population, number of cities and information about per capita urban water supply in states.

To assess the water demand for energy production, study considered the installed capacity of electricity production through coal based and nuclear power plants as the metrics.

Criteria used for each sector are listed below;

Indicator	Criteria
Domestic demand	population of the state, urban population, density, number of cities
Industrial demand	number of water intensive industries, water requirement of the industries
Agriculture demand	area under irrigation of water intensive crops, amount of water required/land, water required for livestock rearing
Energy Production	number of power plants (nuclear, thermal)

Based on the secondary data available for the identified metrics, listed criteria data was collected from secondary sources[5]. Total water demand estimates were calculated for all the states individually for all indicators comprising of the four selected sectors of water use. Based on the total estimate of water demand for each state, scaling of water demand was done using percentile method of statistical analysis. States were ranked on a scale of 1 to 5 for each

[5] Indiastat.com, state environment reports, Census data

identified metrics, with 1 being the least water intensive and 5 being the most water intensive. Hence for each sector, all the states were assigned a score in the bracket of 1 to 5.

Based on the scores received for each sector, a composite scoring was done to get an overall score of state for its water demand intensity. This score was again scaled within the range of 1 to 5, with 1 being the least water intensive state and 5 being the most water intensive state. Each state at the end of this exercise was on the scale of 1 to 5 depending on its water demand using percentile method. Based on this analysis few water intensive states from each geographical zone were screened. This analysis formed one part of the vulnerability index. High water use intensity is one of the vulnerability factors associated with the nexus.

3.1.2 Energy intensive states

Assuming water consumption for electricity production being proportional to the installed and proposed energy production capacity, secondary data was analysed to select the states having high water consumption for energy production. All the states were scored using percentile method, and scaled on a range of 1 to 5.

Finally high energy producing states were selected and then compared with high water intensive states to screen out the common states in terms of having both high water use intensity and high energy production intensity, which makes them more vulnerable.

This led to the development of composite index from the aspect of high water demand and high energy production, which is based on water availability.

3.1.3 Climate change vulnerability

Impacts of climate change on water resources are best reflected through its influence on the annual average temperature, variability in normal rainfall patterns and decrease in snow cover. Rainfall regulates the surface water availability as well as feed into the groundwater aquifer. Hence, rainfall per unit area in a state was taken as the metrics for inferring about the impacts of climate change on a state. Impacts of climate change on the demand patterns were not considered for the study due to limitations in specific data availability. However, as per this approach, states with maximum average rainfall will be more vulnerable to impacts of climate change. Among major Indian states, Kerala, West Bengal, Karnataka, Orissa and Maharashtra, receive maximum average rainfall. In contrast, literature suggests that the basins located in a comparatively drier region are more sensitive to climatic changes due to the impacts on evapotranspiration in the region[6]. Different publications[7],[8] suggest differential impacts on water availability for different river basins. Hence, impacts of climate change were not incorporated to assess the vulnerability of states to water-energy nexus. Moreover, study aims to assess the

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[6] Mall, R.K., Gupta, A., Singh, R., Singh, R.S. and Rathore, L.S. (2006). Water Resources and Climate Change: An Indian Perspective, Current Science, VOL. 90, NO. 12, 25 JUNE 2006.

[7] Gosain A K and Rao Sandya, (2004). Impacts of climate change on water sector. Climate change and India: Vulnerability assessment and adaptation [edts. Shukla et al], University press, New Delhi, pp 159-191.

[8] Climate Change and India: A 4X4 assessment; Indian Network for Climate Change Assessment, 2010

vulnerability of states to linkages of water and energy under the present scenarios, and does not consider the developments in terms of initiatives supposed to be taken by states for water and energy conservation as well as rain water harvesting and renewable energy production. So, impacts of climate change on future water availability or demand patterns has not been considered for the assessment of water-energy nexus for Indian states.

COMPOSITE SCORING-Quantitative Vulnerability Index

Based on all the scoring results obtained using the above listed indicators, a composite scoring was undertaken in each geographical zone to make the WE Vulnerability Index. All the states were distributed in 4 geographical zones so as to get a better representation for country. High scoring states from each zone were pointed as high on WE Vulnerability Index on the scale of 1 to 5, with 1 being least vulnerable and 5 as most vulnerable.

4.0 RESULTS AND DISCUSSION

Based on the four sectors selected for nexus study, all the states were evaluated to estimate the most water and energy intensive states along with estimation of water deficit or surplus and vulnerability to climate change. The results under all the sectors are discussed below.

4.1 Agricultural Production

Agricultural production is the backbone of Indian economy. Agriculture sector contributes to about 15% of country's GDP, with 58% of the population involved in agricultural activities. India produced 241 metric tons of food grains in 2010-11, equivalent to 0.55 kg per capita per day food. The net irrigated area of 58.5 million ha in India comprising 40 % of net sown area contributes 60 % to the food-grain production. However, food grain production is highly variable due to its significant reliance on monsoon patterns, with only 45% of net sown area under irrigation. Also, local food habits play a determining role in the type of crop being grown in a state.

Two dominant staple crops in the country- Rice and Wheat, and two water intensive cash crops- sugarcane and cotton, were selected for the assessment of water dependence of agriculture in different states. Also, total production of animal husbandry products and horticultural products was accounted for total agricultural water requirement. As different crops have difference in area under irrigation, in different states, percentage area under irrigation was used. The different states with high dependence of their agriculture on water are Uttar Pradesh, Maharashtra, Tamil Nadu, Karnataka, Punjab and Andhra Pradesh.

4.2 Industrial Production

According to a latest report of UNIDO, India is amongst the top 5 developing countries in the production of six basic industrial items including textile, chemicals, and base metals. Manufacturing units have shown a tremendous growth of 42.67% in a span of 20 years (1987-

2007).[9] The industrial sector in India is the second highest user of water after agriculture.[10] Groundwater is the major source of water for the industries. Industrial water consumption is expected to quadruple between 2000 and 2050. It is reported that by 2050 industrial water consumption will reach 18% of total annual water consumption, up from just 6% in 2000.[11] However, water consumption differs in different type of industry. Thermal power, textiles, pulp and paper, iron and steel, and fertilizer industries are highly water intensive industries.

As data on water consumption in individual industrial sectors is missing, an attempt was made to estimate the relative water demand by estimating the number of industrial units established in the state and it's installed or production capacity. Based on the overall composite score of all the four selected water intensive industrial sectors (textile, pulp & paper, iron & steel, and fertilizers), following states were found as water intensive states in terms of water consumed for industrial production; Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra, Uttar Pradesh. (in decreasing order)

4.3 Demography of States

India is second most populous country of the world, with a decadal growth rate of 17.64% from 2001-2011. There exists a wide variation in different demographic characteristics across different states in the country. Uttar Pradesh, Maharashtra, Bihar, West Bengal and Andhra Pradesh are the five most populous states of the country. Together these five states have contributed almost 50% of the population to the decadal growth.

Density of population in these states varies in proportion to their size. Three of the most populous states viz., Bihar, West Bengal and Uttar Pradesh, are most densely populated states also. States which follow the sequence are Punjab, Haryana and Tamil Nadu; with density almost half of the most densely populated state.

Rural-Urban population distribution in the country is 69%-31%. During 2001-2011, the proportion of urban population has increased by 3% points, with 377 million people living in urban areas. Maharashtra, Uttar Pradesh and Tamil Nadu recorded maximum urban population in 2011, which may be due to migration, natural increase or inclusion of new areas as urban.

Thus, varying scenarios develop during assessment of individual demographic characteristics, having an influence on water availability and demand patterns. A composite score was developed for all the states based on their individual ranks and scores for identified metrics (Figure 3). States with highest composite score based on their water demand for urban population were Uttar Pradesh, West Bengal, Tamil Nadu, Maharashtra, Bihar and Andhra Pradesh.

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[9] Report of the working group on "Effectively Integrating Industrial Growth and Environment Sustainability", Planning Commission

[10] India's deepening water crisis, FICCI, CWC Report, 2012

[11] Water- the India Story , 2009, Grail Research

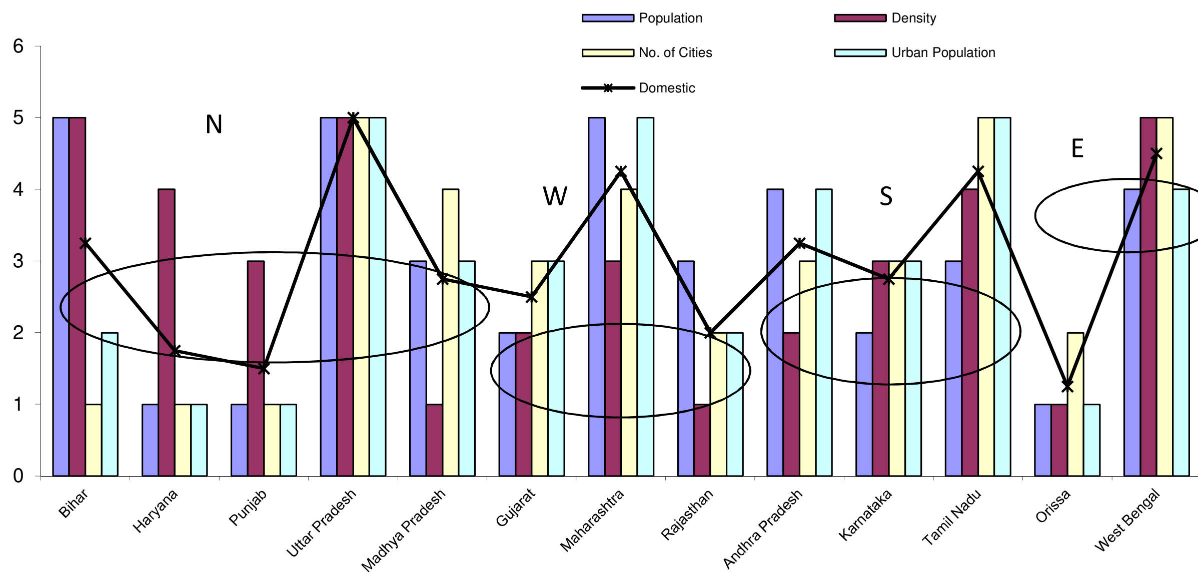

Figure 3: Zone-wise composite score for domestic water demand in states

4.4 Energy Production

Energy production sucks up about 15 percent of the world's total water withdrawal[12]. With almost one-fifth of the world population, India ranks fourth in the world in terms of energy demand. In 2011-12, India produced 877 billion KWh of electricity, out of which 85% was through thermal and nuclear power plants. With its economy projected to grow by 7%-8% over the next few decades, demand for electrical energy is likely to be 1915 Tera Watt Hours with a peak electric demand of 298 Giga Watts. For meeting the growing needs of the economy, Government of India plans to double the electricity generation capacity every ten years for next three decades at least. To achieve this goal, it plans to develop Ultra Mega Power Projects (UMPPs) with capacity of 4000 MW each and involving an estimated investment of about $ 4 bn. Thirteen such thermal power projects have been envisaged which are at various stages of development. States where these power projects are proposed are Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh, Jharkhand, Madhya Pradesh, and Orissa.

Water is used intensively for thermal and nuclear power generation. It is estimated that on an average, for every 1 kwh power, Indian thermal power generation plants (TPPs) consume as much as 80 litres of water. So depending on the state wise installed capacity of the thermal and nuclear power plants (which contributes to 85% of the electricity produced), following states can be categorised as water intensive states in terms of energy production, Maharashtra, Gujarat, Uttar Pradesh, Andhra Pradesh, West Bengal. (In decreasing order)

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[12] International Energy Agency Report

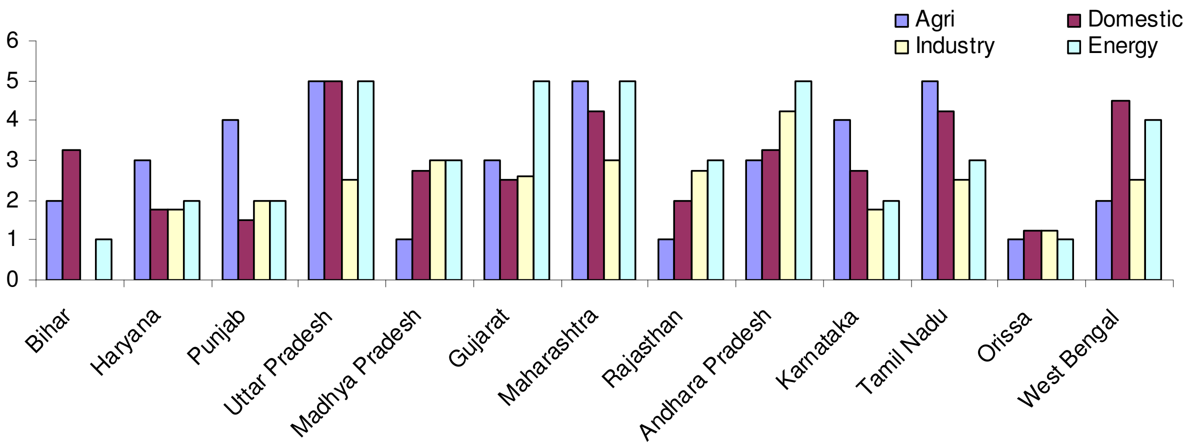

Figure 4: State-wise scores for sectoral water demand

4.5 Water Distress

Availability of water is a major concern for driving any process. If available water in the state is not able to meet the demands from all the sectors then that state is referred to as water deficit state where as if the state has more available water than demand then that state is referred to as water surplus state. Moreover, the deficit or surplus of water in comparison to the total water required for energy production, will determine the water-energy stress and the vulnerability of state to water-energy nexus.

Difference of score for water availability and total water demand was taken as indicator of deficit or surplus of water for a state. Comparison of this difference with the score of water demand for energy production determined the vulnerability of state to water-energy nexus. Based on this estimation, states found to be most vulnerable to water-energy nexus are Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh, Karnataka, Rajasthan and Uttar Pradesh (in decreasing order).

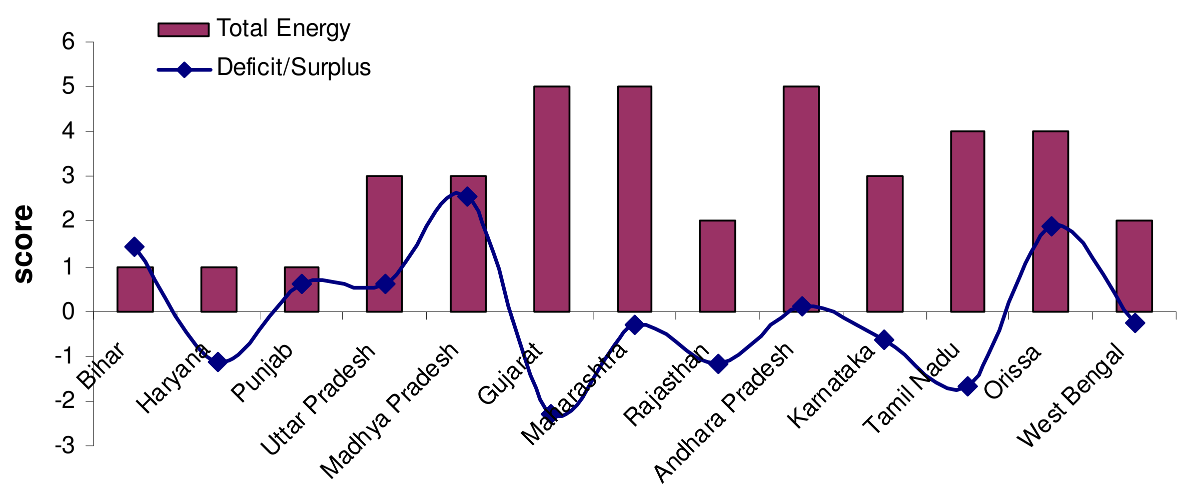

Figure 5: Water deficit/ surplus vs Total energy production indicating the vulnerability to Water-energy nexus.

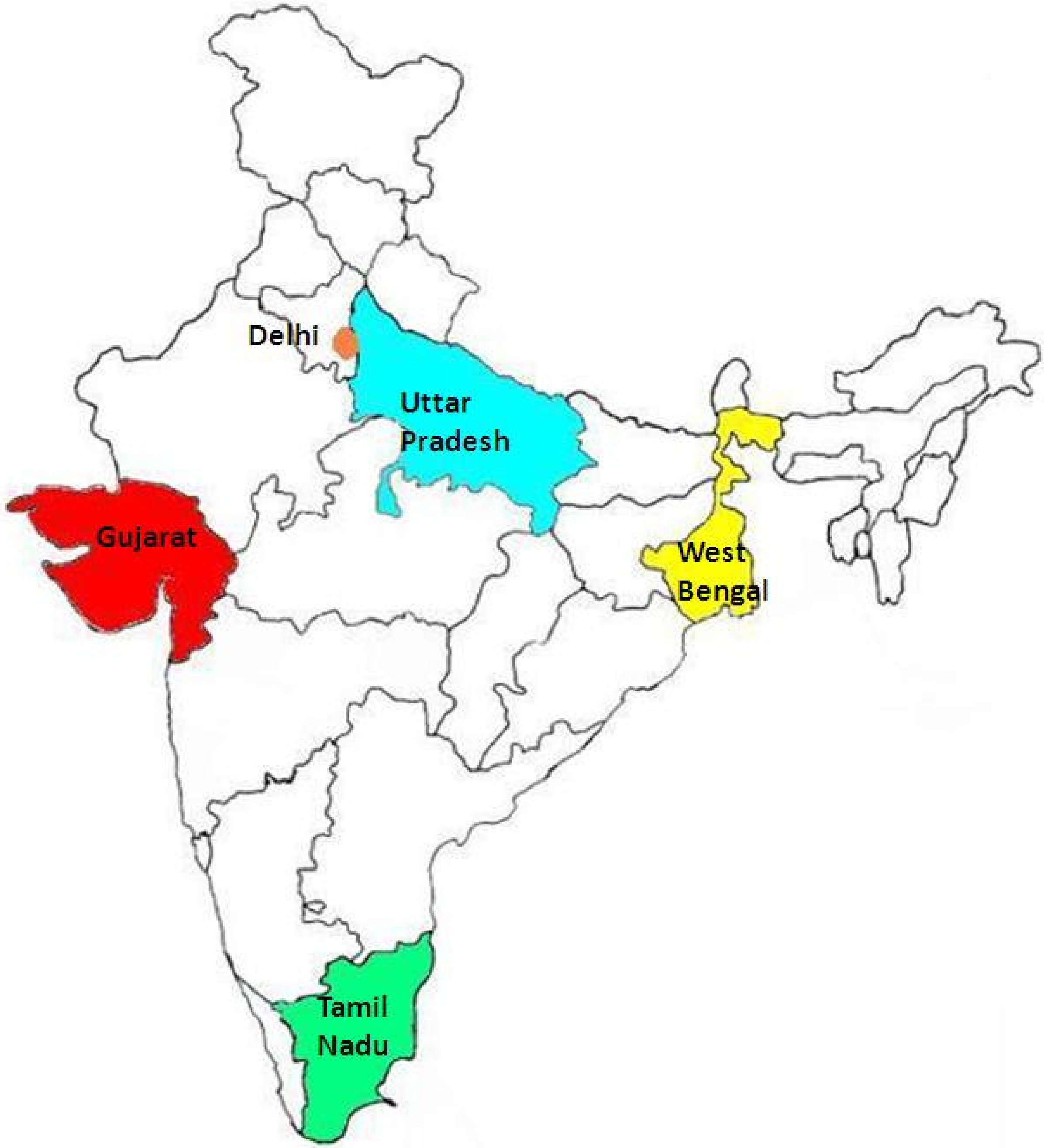

Figure 6: States (zone-wise) selected as most vulnerable to water-energy nexus

5.0 Conclusion

States in southern and western parts of the country are specifically vulnerable to water-energy nexus. This is mainly due to coupling of total water availability, water demand from different sectors and water demand for energy production. Individually, different states occupy different ranks in terms of water availability or demand for specific sectors including for energy production. However, a composite scoring reveals different scenarios for water-energy nexus vulnerability. For example, Andhra Pradesh is marginally water surplus state but owing to high energy production capacity, it is vulnerable to water-energy nexus.

However, states were categorised into different zones- North, South, West and East India. One state was selected from each zone for the purpose of detailed study. These were the states most vulnerable to water-energy nexus. The states selected for detailed evaluation and of water-energy nexus footprinting are Uttar Pradesh in North, Gujarat in west, Tamil Nadu in south and West Bengal in east.

The states with higher degree of vulnerability show greater and intricate dependence between the components of nexus, and reflect risks associated with water and energy security. The selected states will be studied to understand the nexus better through stand-out case studies. These case studies will demonstrate the intricacy of nexus and will help in understanding the risk and planning the adaptation strategies.