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Vulnerability of Watersheds to Climate Change Assessed by Neural Network and Analytical Hierarchy Process

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Vulnerability of Watersheds to Climate Change Assessed by Neural Network and Analytical Hierarchy Process

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Preface

The climatic variations caused by the global warming has attributed to various vulnerabilities among which the impact is optimum in case of watersheds. Any living entity is dependent on the water system to sustain their livelihood. Owing to the weaknesses in the watersheds, both “quantity and quality” of the “liquid gold” has receded. Many places which were once prosperous with clean water are now experiencing acute scarcity of the assets.

Although the weaknesses in the watershed are intense, due to the dearth of appropriate overseeing methods, the vulnerabilities imposed because of the changes in climate are detected late and the impact becomes enormous and goes beyond control. Most of the methods or indicators developed to identify the exposures of watersheds have multiple lacunae. Either some parameters are missing, or all the variables are assigned the same relevancy or require complex calculation which confuses the end users to estimate vulnerabilities with the help of indicators, or often temporal or spatial or scale-restricted beacons are developed. Different pointers were also found to be discriminatory and alterable so that biased outcomes can be yielded. Above all, nearly all the omens were found to be abstract and imprudent.

That is why, the present study attempts to develop an indicator which follows a specific procedure to identify the most substantial parameters such that no imperative parameter is missed out. The new and novel approach assigns specific importance based on relevance of the variables and has some simple calculations to estimate the status of the watersheds. The omen was made objective by the application of multi-criteria decision-making and also made judicious (artificial neural network) so that indiscriminate and reasonable but contemporary information about the watersheds can be retrieved.

In the first chapter the problem and the solution was proposed by discussing the pertinent points and reviewing the available and related literatures. The justification of the MCDM and ANN applications was also proposed. The first chapter also introduces the new method and the steps followed to achieve the objective of depicting the status of watershed vulnerabilities briefly.

The second chapter is an overview of the concept of climate change. The causes and the effects of the climatic alteration were described. Both the models, global and regional (GCM and RCM), which are used to predict the future climate, were included. This chapter also discusses about the Intergovernmental Panel on Climate Change (IPCC) and the scenarios proposed by the committee. The A1, B1 and A2, B2 scenarios were discussed and the impacts were analyzed as the present study predicts the vulnerabilities of the watershed based on the IPCC scenarios.

The watersheds have different functions which ensure sustainability in the living beings. The capabilities are crucial and ascertain the storage and production of usable water in sufficient quantity so that the requirement of each of the living subsistence can be contented. But due to rapid urbanization, natural traits of land attributes are transforming at a quicker rate. The land use is altering due to industrialization, slope of the land has been receded in many places to accommodate the excess population which has also resulted in the reduction of infiltrable area. The variations in the pervious area have contributed to the increase in volume of run-off from the watersheds. As the number of dependents have increased the stress on the natural resources have also been increase. That is why, the per capita water obtainable has reduced compared to the water availability per person that was observed in the last decade. In Chap. 3 the functions of watersheds and the indicators utilized to depict the status of watersheds were mentioned. The discourse highlighted the drawback of the existing indicator in detail.

The methodology for the development of the novel indicator was discussed in depth. The queries like "How the parameters were selected?", "How the MCDM were ascribed?", "How the weight function is applied as the indicator?", "How the ANN was implemented?" and "What locations were taken as study area?" were answered in the chapter on methodology.

The results and the discussions of the results were given in Chap. 5, followed by the conclusions drawn based on the results depicted in the last chapter.

Overall it was found that the novel indicator can become a tool which can reliably depict status of watersheds in face of climate change as well as urbanization and financial implications. The applications of the indicator will reduce the cost of mitigation projects and will also ensure optimal allocability of the funds.

Acknowledgments

This book is about vulnerabilities from climate change and the process we may adopt to discover and offset the effects. That is why, first of all, we want to profess the contributions of all those people who are working day and night to help individuals realize "what" a climate change is and "how" such alterations will affect us in the future.

I express my earnest gratitude to our publisher for granting the book for publication and offering me a platform to showcase the efficiency and efficacy of a novel indicator in the prognosis of the exposures that may be imposed on watersheds due to the climatic variations.

I also like to recognize the contribution of the reviewers who have so painfully gone through the manuscript and suggested changes which has greatly improved the readability and technical proficiency of the monograph.

We also consider the benefits of the data and information which we have collected from various sources to validate the indicator. So I will like to take this opportunity to recognize not only the publishers and producers of the different documents which I have already referred in the book but also the documents which I had missed out.

Last but not least, we express our strongest appreciation to our families, friends and colleagues and without their cooperation this project may have never seen the light of proclamation.

Kolkata, India — Mr. Uttam Roy
Agartala, India — Dr. Mrinmoy Majumder

Contents

Chapter 1
Introduction

Abstract The present study is an attempt to assess the vulnerability of watersheds in face of climate change and change in urbanization with the help of multi-criteria decision-making and artificial neural networks. The study was carried out keeping in view the scarcity in amount of water and degradation in quality of water observed in different watersheds in various parts of the World due to the onset of climatic vulnerabilities and rapid change in urbanization. An indicator was also proposed and a model was developed linked to the indicator. The said indicator is objective, relative and cognitive in nature so that it can depict accurate representation of the status of any watershed. The study results provided a platform to uniformly rate different river basins in terms of climate change and urbanization which in turn will help to mitigate the disasters by concentrating funds and energy to the locations where it is really required.

Keywords Watershed vulnerability · Multi Criteria Decision Making · Artificial Neural Networks · Indicator

1.1 Introduction

The density of population worldwide is increasing at a rapid rate. The increase in population also aggravated the demand for food and land. This rising demand was satisfied by converting the nature of land use from forest to agriculture or industry. The change in land use has also decreased the area of forest cover and increased the rate of erosion. On the other hand, wide-scale extraction of natural resources to provide the increasing demand for energy and luxury also imbibed large-scale reduction in forest cover.

The increasing population has also incremented the rate of urbanization. The lack of source of income in the rural areas as well as forced displacement due to conversion of land use can be attributed for this self-aggrandizing change in the rate of urbanization.

But urbanization and the extraction of natural resources has severely affected the retention capacity of watersheds which have decreased the capacity of storing water

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in many of the major watersheds of the World. The decrease in forest cover and increase in industrial concentrations has induced increase in the concentration of GHG gases in the atmosphere. As greenhouse gases (GHG) can block the return of thermal energy from earth crust to space, the average temperature of the atmospheric region tends to increase causing a worldwide phenomenon known as global warming or cooling.

The impact of this global warming or cooling is felt in the climatic pattern of a region which changes due to the change in temperature. The climatic abnormality can affect the amount of water availability in watersheds.

1.1.1 Signs of Climate Change

Ninety-seven percent of climate scientists agree that climate-warming trends over the past century are very likely due to human activities, and most of the leading scientific organizations worldwide have issued public statements endorsing this position.

The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7,000 years ago marking the beginning of the modern climate era—and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives.

The impact of change in regular pattern of climate is now visible in many parts of the World. The changes are mainly observed in the following areas:

(a) Sea level rise (Fig. 1.1)
(b) Increase in rate of acidification of oceans (Fig. 1.2)
(c) Decrease in snow cover (Fig. 1.3)
(d) Effect on food products (Fig. 1.4)
(e) Rise in air temperature (Fig. 1.5)
(f) Early onset of season (Fig. 1.6)

The impact of climate change is now affirmed worldwide. Signs like shrinking of snow cover (NASA 2014), early onset of season, rise in sea level, decrease in crop yield (Greenway 2014), etc. indicate that climate is changing and it has some noticeable impacts that can increase the number of extremities and may induce hazards in the human livelihood.

1.1.2 Climate Change and Its Impacts

The unrestrained removal of natural resources, non-moderated growth in industrial activities, destruction of natural forest and water bodies followed by the rising

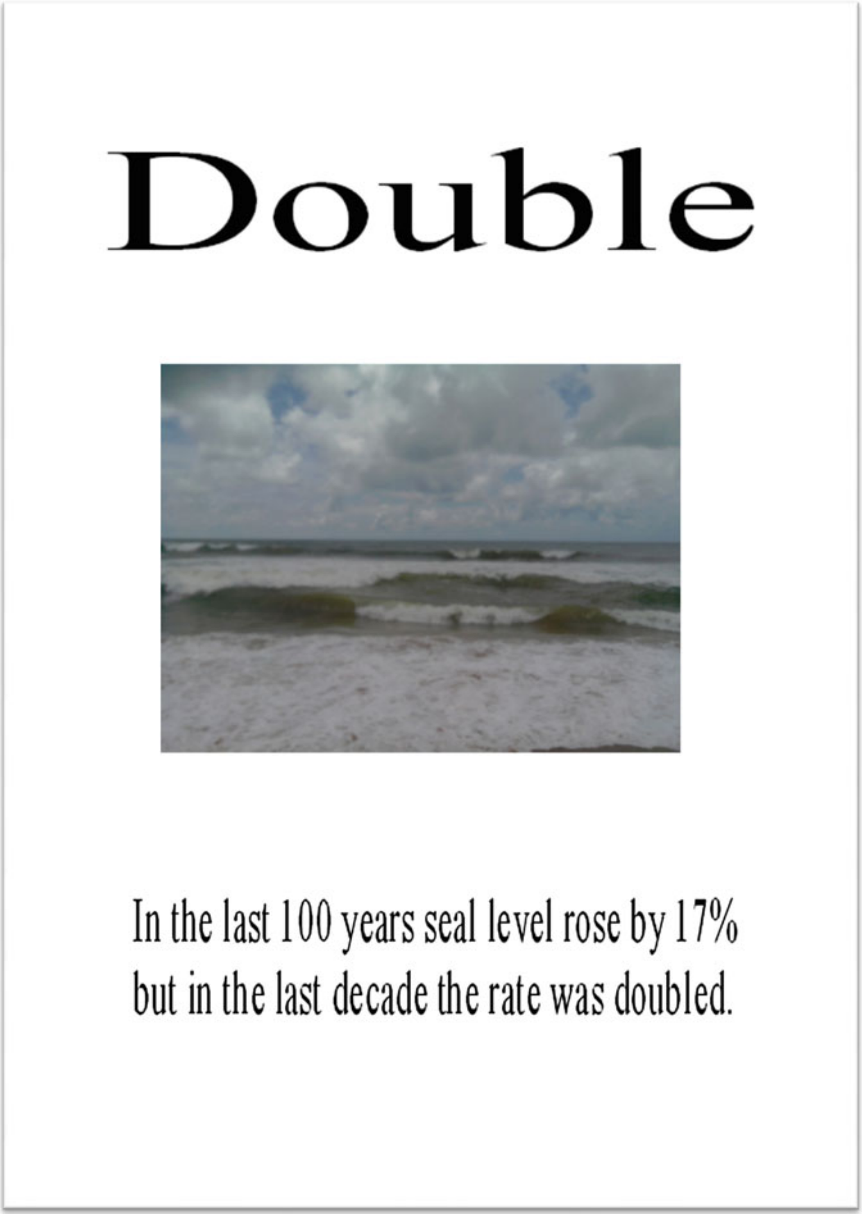

Fig. 1.1 Sea level rise

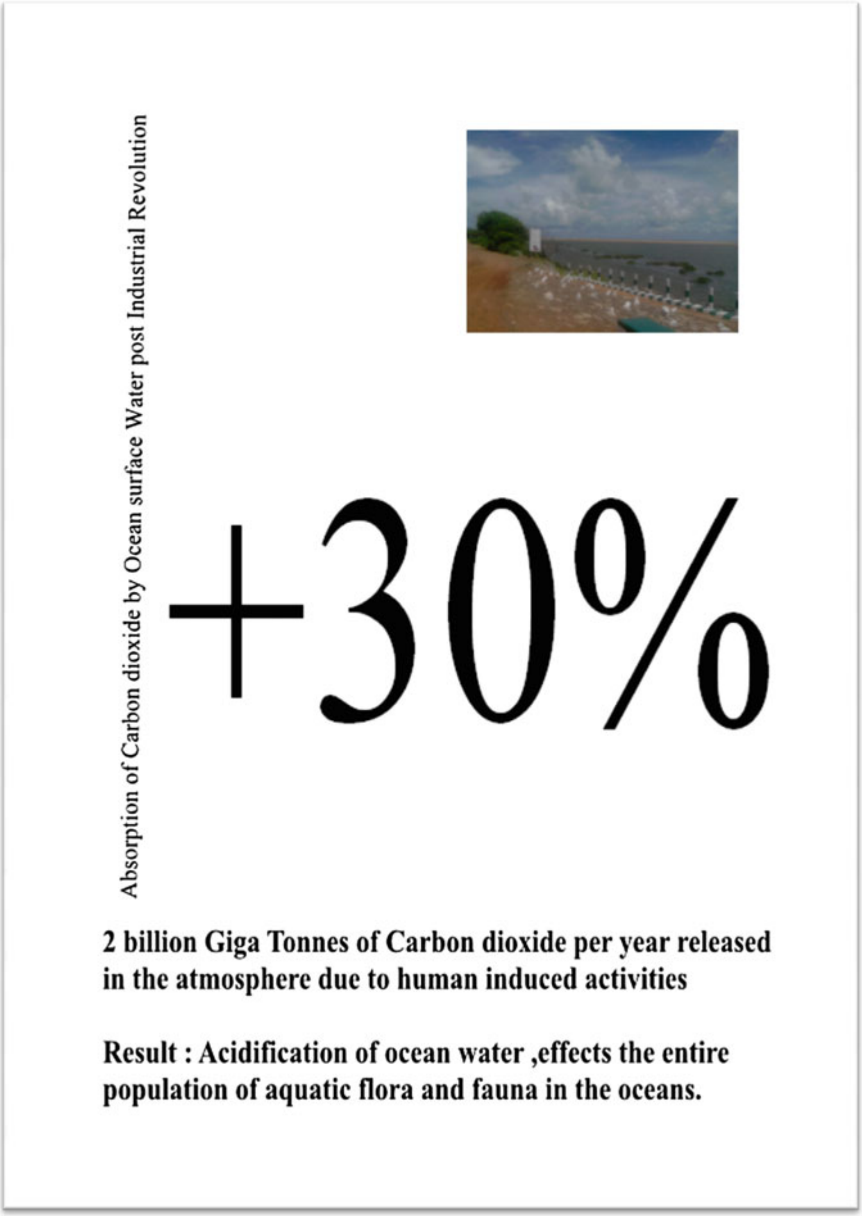

Fig. 1.2 Ocean acidification

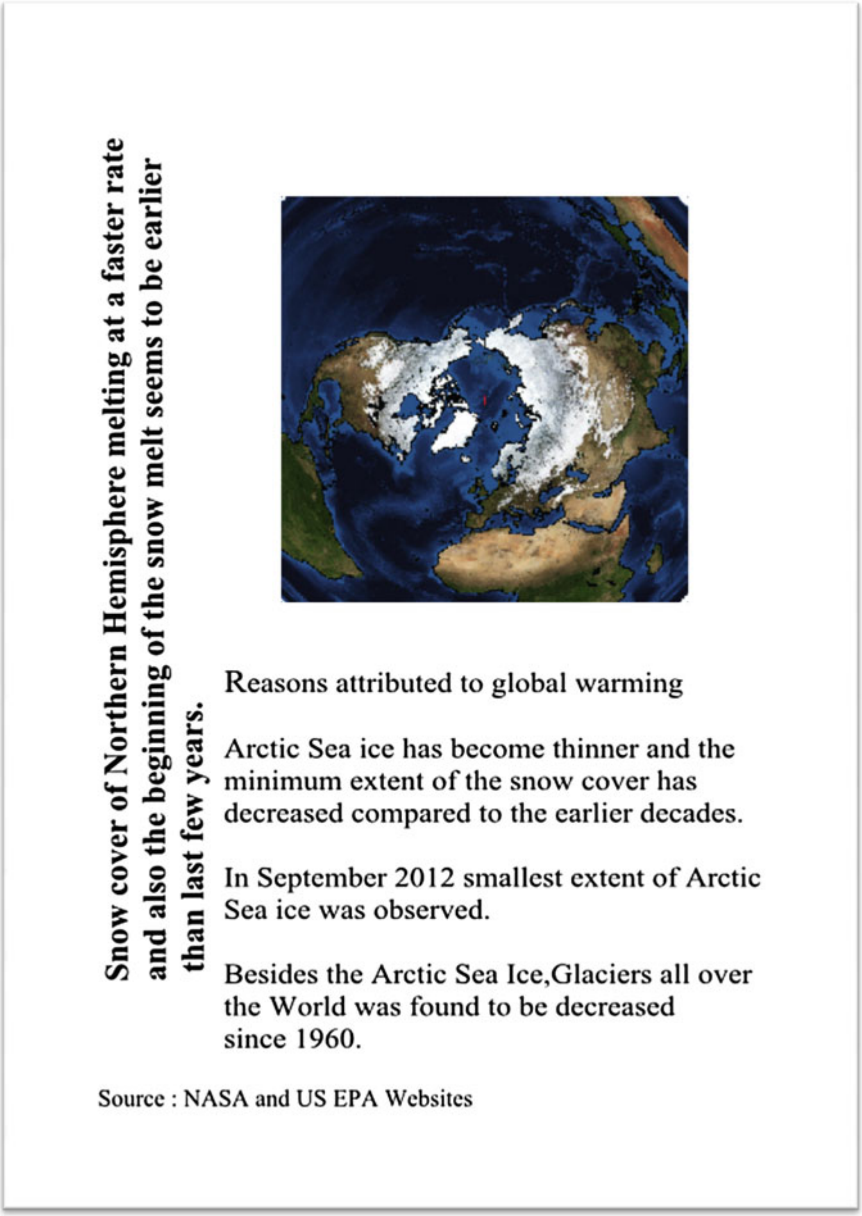

Fig. 1.3 Signs of snowmelts

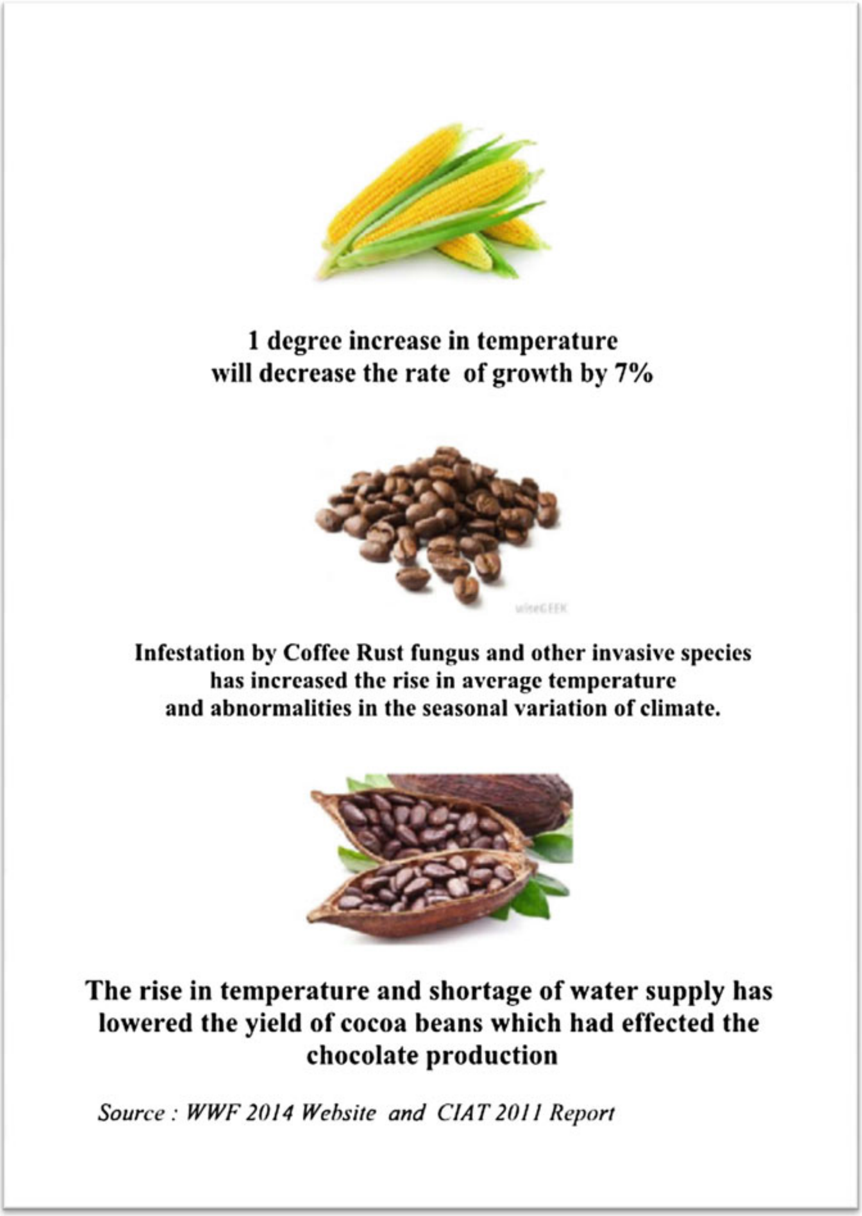

Fig. 1.4 Effect on food

Fig. 1.5 Rise in temperature

Fig. 1.6 Shifting of season

demand for water and energy from the ever-growing population to sustain their livelihood as well as luxury and current technological developments has enhanced the stress on water resources of the majority of the countries in the World. The usage of fossil fuel has increased many-fold in comparison to the previous decades and as a result quantity of greenhouse gas in the natural environment has increased. The greenhouse gases or GHG is responsible for raising atmospheric temperature. It also prevents the release of heat from the earth crust. Thus raise in GHG level can cause global warming or cooling. The warming or cooling of atmosphere will certainly change the regular climatic pattern. The change in climatic pattern will induce abnormality in the precipitation as well as evaporation patterns of any region which will again impose variations in the available volumes of freshwater.

Climate change can create vulnerabilities to:

1. Native **people, facilities, agribusiness and recreational activities. It will likely put extra stress on infrastructure and the economy**.
2. Wildlife, for example, **Arctic polar bears are under the threat of extinction and golden toad** has gone extinct.
3. The **level of areas prone to desertification and the extremity of desertification in the current arid lands.**
4. **Water scarcity** in the Mediterranean due to shortage of water as well as degradation of water quality caused by saline water intrusion.
5. Rise in temperature as projected by the IPCC in 2013 **in the next 80–90 years will be larger than the Paleocene/Eocene extinction event that occurred 56 million years ago, but the change in the climate in the recent years is occurring 100 times faster than then**.
6. **Hazardous weather events will become more regular or extreme.** Heat waves in Australia and increased occurrence of extreme events in the America can confirm this prediction.
7. The climate change will aggravate the risks of floods and landslides.
8. In less prosperous regions, where countries lack the resources and capabilities required to adapt quickly to more severe conditions, the problem is very likely to be exacerbated.

Unfortunately, the mostly middle-class environmental movement and corporate-backed politicians have shown little sensitivity to the pursuits of labour as they planned to propose public policy responses to climate change. The clear and increasingly impending threat should be of worry to everyone on the planet but particularly to those who live close to the oceans and bays due to their exposure to soaring water levels.

Although the "scientific consensus" in 2009 is that the planet's atmosphere is warming, opinion seems to suggest a correlation to human lifestyle.

1.1.3 Watershed Vulnerabilities

Flooding and erosion are the two major hazards that can occur in a watershed and can make it vulnerable to disasters. The vulnerabilities of watershed is a popular topic of research, as most of the people in the World reside in the river basins. Any vulnerability to the watershed will severely impact the regular livelihood of the people living there.

Threats directly associated with flooding and erosion include property damage, personal injury, or loss of life, as well as impacts to water quality and the area's animals and plants;

Floods happen when water levels rise and cover the land—the floodplain—adjacent to a river, stream, or lake;

Floodplains are Nature's way of slowing and dealing with the onslaught of extra water that comes from extreme rainfall or snowmelt, or as the result of debris (natural or otherwise) or ice blocking a watercourse;

Erosion (an important natural process) increases during floods, including when the torrent of extra water does not overflow a stream's or river's banks onto the floodplain;

Increased erosion can weaken the stability of stream banks and other slopes by, for example, interfering with the slope's drainage system. Weakened banks and slopes have an increased risk of failure;

Land use changes (associated with how we live and grow in an area) and climate change (now associated with an increase in the number and severity of storms we experience) are the two important parameters that affect the status of watersheds.

There are many publications which monitor the vulnerabilities of watersheds after a flood or some other extreme events like hurricanes or landslides, etc. (Conservation Ontario 2009; VT DEC, n.d., Prevention Web 2007).

In a study Pasco and Nida (2011) highlighted the critical factors of watershed vulnerabilities which are depicted below:

1. Physical critical factors: slope, rainfall, land use, soil type and geology
2. Anthropogenic critical factors: farming system/land use and road network

Besides the above studies, Table 1.1 depicts a series of studies which are conducted to identify different types of vulnerabilities of watersheds.

1.1.4 Indices Representing Watershed Vulnerability

He et al. (2000), Schultz et al. (2001), King et al. (2005), Heede (1975) and Chaves and Suzana (2007) developed an indicator to represent the status of the watersheds in term of the water quantity and quality.

The indicators of watershed must represent the status with respect to the hydrological, environmental, life and policy matters so that it can provide sufficient information regarding the main goal of any watershed management programme:

Table 1.1 Table showing different studies conducted to assess vulnerabilities of watersheds

Sl. No.	Authors	Location	Vulnerability factor	Research outcome
1.	Junior et al. (2015)	North-east Portugal	Ground water contaminants as electrical conductivity, sulphate and copper	Most of the region was weakly vulnerable except the areas which are in direct contact with the alluvium, granites and metasediments
2	Sanchez et al. (2015)	North America	Population of aquatic flora and fauna	Both are vulnerable to developmental activities in the watershed
3	Narmada et al. (2015)	South India	Land quality and water resources	Identified the vulnerable regions with the help of specific land parcels connected to land uses
4	Hoque et al. (2012)	North America	Water quality	Sedimentation problem
5	Tran et al. (2012)	Mid-Atlantic	Environmental parameters	Vulnerable to environmental problems
6	Tilt (2012)	South-west China	Biodiversity, economy, governance and public participation and cultural autonomy	The impact of a proposed 13 dam cascaded hydropower project which will generate 21000 MW of power but will displace 50,000 people and may remove 7000 plant species, 80 species of rare and endangered animals and 22 of 55 officially recognized ethnic communities was discussed. The socio-economic and biotic parameters indicates a large-scale vulnerability if the project is originally installed in the region
7.	Chang and Hsu (2010)	Southern Taiwan	Meteorological and geographical factors	The factors helped to separate the watershed which are highly, moderately and lowly vulnerable to developmental activities
8.	Kaushik et al. (2005)	Himalayan region in India	Parameters like land use and cover, soil erosion, etc. which represents the natural hazards are taken as the input factors.	Hazards like depletion of forest cover, land slides, erosion, etc. can be identified with the multiple hazard representing GIS maps

Table 1.2 Table showing the application of indicators to represent different aspects of watershed management

Author	Name of the indicator	Indicates/represents	Location of application
Niemi et al. (2015)	Environmental indicator for US Great Lakes basin	Environmental sustainability	Coastal regions of US Great Lakes, USA.
Masoud and Amiri (2015)	Dpsir	Hazard due to vegetation degradation	Sadra Region, Iran
Mayer et al. (2014)	Integrated social and biophysical indicators	Impact of socio-economic status of the watershed on water resources, biophysical, demographic, land use and social parameter	US Great Lakes
Vernier et al. (2013)	EIS pesticides: agro-environmental indicator	Characterize agriculture activities specially the impact of pesticides.	Charente watershed and its sub-basins in France
He et al. (2000)	Integrated ecological indicators	"Spatial and temporal distributions of hydrological and biological conditions which result from land use/cover changes across the study watersheds"	China

sustainability assessment and development of the present generation without compromising the ability of future generation to satisfy their needs (Yusoff and Zardari 2015).

The Human Development Index used by UN represents only life and policy status of the people living in the watershed whereas Water Poverty Index (Sullivan 2002), Canadian Water Sustainability Index (PRI 2007), etc. indicate the water resource status of the basin. The Water Quality Index (Ling 2007) deals with the water quality issues. But all these indices have two common drawbacks: (1) They are either temporal or spatial; (2) All the important factors of watershed management are not represented in an integrated manner.

Table 1.2 depicts the application of indicators to represent various aspects related to watershed vulnerability.

1.1.5 Objective of the Present Investigation

The proposed new method applies analytical hierarchy process (AHP) to find the priority values of the parameters after comparing relatively with each of the alternatives and criteria. The parameters were selected based on literature review and reports.

The artificial neural network (ANN) was used to predict the index where inputs are known but output is unknown. Both AHP and ANN were used simultaneously to find the area of watershed which is severely affected by the change in climatic pattern.

The vulnerability in this regard was estimated by the weighted average of the selected parameters. The change in vulnerability is made to be directly proportional with the value of the index.

The novelty of the study can be depicted by the first time use of AHP cascaded with ANN to estimate the vulnerability to climate change of watersheds. The selected criteria were not yet used in any related study for analysing the alternatives/factors.

The use of ANN on the other hand is for the first time the technology provided a portable arrangement to measure and estimates the indicator which is directly proportional to the climatic vulnerability.

1.1.6 Brief Methodology

As a first step of the study a thorough metastatic analysis was conducted. From the metastatic analysis the important parameters were selected. The selected parameters are then compared with each other to get the priority values of each of the parameters by AHP MCDM method.

In the next step the criteria for which the factors will be analysed is determined and the ANN model is developed with combination of multiple types of training algorithms and poly-numeric architecture. The data for training was provided by random compilation of different situations that may arise in the selected study area.

The input data for the future situations were collected from different reports and data provided by various governmental collections. As the weights are already estimated the data values of the input parameters are used to calculate the index value.

The impact of climatic uncertainty is depicted by the data collected from PRECIS climatic model with respect to the scenarios proposed by Intergovernmental Panel on Climate change (IPCC).

The future and present data for the present location was used to estimate the value of the indicator with respect to change in climate. IPCC A2 and B2 scenario was selected for which the value of the indicator is used to show the status of the vulnerability of the watershed.

References

Chaves, H. M. L., & Alipaz, S. (2007). An integrated indicator based on basin hydrology, environment, life, and policy: The watershed sustainability index. *Water Resources Management, 21*(5), 883–895.

Greenaway, T. (2014). Eight foods you're about to lose due to climate change. Retrieved from http://www.theguardian.com/vital-signs/2014/oct/29/diet-climate-maple-syrup-coffee-global-warming.

Heede, B. H. (1975). Watershed indicators of landform development.

King, R. S., et al. (2005). Spatial considerations for linking watershed land cover to ecological indicators in streams. *Ecological Applications, 15*(1), 137–153.

NASA. (2014). Global Climate Change: Vital Signs of the Planet. Retrieved from http://climate.nasa.gov/evidence/.

Pasco, M. M., & Picut, N. G. (2011). Vulnerability assessment of Cugman River Watershed. *IUFRO World Series, 29*, 50.

Schultz, M. T. (2001). A critique of EPA's index of watershed indicators. *Journal of Environmental Management, 62*(4), 429–442.

Prevention Web. (2007). Preparing for flood disaster: Mapping and assessing hazard in the Ratu watershed, Nepal. http://www.preventionweb.net/english/professional/publications/v.php?id=9295.

Conservation Ontario Report. (2009, August). Natural Hazards. Retrieved from http://www.conservationhalton.ca/natural-hazards.

Chang, C.-L., & Hsu, C.-H. (2010). Applying a modified VIKOR method to classify land subdivisions according to watershed vulnerability. *Water Resources Management*, *25*, 301–309.

He, C., Malcolm, S. B., Dahlberg, K. A., & Bojie, F. (2000). A conceptual framework for integrating hydrological and biological indicators into watershed management. *Landscape and Urban Planning, 49*(1–2), 25–34.

Hoque, Y. M., Tripathi, S., Hantush, M. M., & Govindaraju, R. S. (2012). Watershed reliability, resilience and vulnerability analysis under uncertainty using water quality data. *Journal of Environmental Management*, *109*, 101–112. Retrieved October 30, 2012.

Junior, R. F. V., Varandas, S. G. P., Fernandes, L. F. S., & Pacheco, F. A. L. (2015). Multi Criteria Analysis for the monitoring of aquifer vulnerability: A scientific tool in environmental policy. *Environmental Science & Policy*, *48*, 250–264. Retrieved April, 2015.

Kaushik, P., Joshi, P. K., & Yang, X. (2005). Multiple hazard mapping (MHM) for vulnerability assessment in Pali Gad watershed using geospatial tools. *Journal of the Indian Society of Remote Sensing, 33*, 441–445.

Ling, L. F. (2007). Comparison of Water Quality Index (WQI) between DOE Method and Harkin's Index. Master Thesis, Universiti Teknologi Malaysia.

Masoudi, M., & Amiri, E. (2015). A new model for Hazard evaluation of vegetation degradation using Dpsir framework, a case study: Sadra Region, Iran. *Polish Journal of Ecology, 63*(1), 1–9.

Mayer, A., Winkler, R., & Fry, L. (2014). Classification of watersheds into integrated social and biophysical indicators with clustering analysis. *Ecological Indicators, 45*, 340–349.

Narmada, K., Gobinath, K., & Bhaskaran, G. (2015). An assessment of resource potentials for sustainable development of micro-watershed in Tirunelveli District using geoinformatics—a case of Nambiyar micro-watershed in Tirunelveli District, Tamil Nadu. *Aquatic Procedia, 4*(2015), 1299–1306.

Niemi, G. J., Johnston, C. A., & Wolter, P. T. (2015). Development of Environmental Indicators for the US Great Lakes Basin Using Remote Sensing Technology.

Policy Research Initiative, Sustainable development briefing note. Canadian water sustainability index. (2007). http://publications.gc.ca/collections/Collection/PH2-1-14-2007E.pdf. Retrieved December 30, 2013.

Sanchez, G. M., Nejadhashemi, A. P., Zhang, Z., Marquart-Pyatt, S., Habron, G., & Shortridge, A. (2015). Linking watershed-scale stream health and socioeconomic indicators with spatial clustering and structural equation modelling. *Environmental Modelling & Software*, *70*, 113–127. Retrieved August, 2015.

Sullivan, C. (2002). Calculating a water poverty index. *World Development, 30*(7), 1195–1210.

Tilt, B. (2012). Damming China's Angry River: Vulnerability in a Culturally and Biologically Diverse Watershed. In *Water, Cultural Diversity, and Global Environmental Change*.

Tran, L. T., O'Neill, R. V., & Smith, E. R. (2012). A watershed-based method for environmental vulnerability assessment with a case study of the Mid-Atlantic region. *Environmental Impact Assessment Review*, *34*, 58–64. Retrieved April, 2012.

Vernier, F., Miralles, A., Pinet, F., Carluer, N., Gouy, V., Molla, G., & Petit, K. (2013). EIS Pesticides: An environmental information system to characterize agricultural activities and calculate agro-environmental indicators at embedded watershed scales. *Agricultural Systems, 122*, 11–21.

Yusoff, S. M. A. M., & Zardari, N. H. (2015). Trend analysis of publications on watershed sustainability indicators in popular academic databases. In *ISFRAM 2014*, pp 19–29.

Chapter 2
Climate Change and Its Impacts

Abstract The present chapter deals with the concept of climate change and its modelling. The change in climate and its impacts are now observed all over the World. Increase in extreme events, change in start of season etc depicts that climate is in a transitional mode. As an impact of climate change the quantity, quality of water along with security of food and quality of life is being hampered. There are various models to predict future climate so that the forthcoming disasters can be either avoided or effects from the same can be mitigated. The models like global and regional circulation models help users to predict globally and locally the future climatic parameters like rainfall and temperature. Intergovernmental Panel on Climate Change Scenarios was developed so that the status of the word can be simulated based on the different scenarios like industrial, environmental and mixed.

Keywords Climate models · IPCC · Change in climate

2.1 Climate Change: Cause and Effects

Figure 2.1 depicts a pictorial representation of the cause and effects of climate change. There are two types of causes of climate change, natural and human-induced causes. The change in climate due to global warming is an example of human-induced causes.

Other than causes, there are two types of forcers caused by long- and short-lived substances. The global warming is caused by both types of forcers. But short-lived substances like aerosols can also cause global cooling.

The change in climate can impact various aspects of biotic sustenance. The climate change can impact hydrological cycle, watershed health and many other related phenomena as shown in Fig. 2.1.

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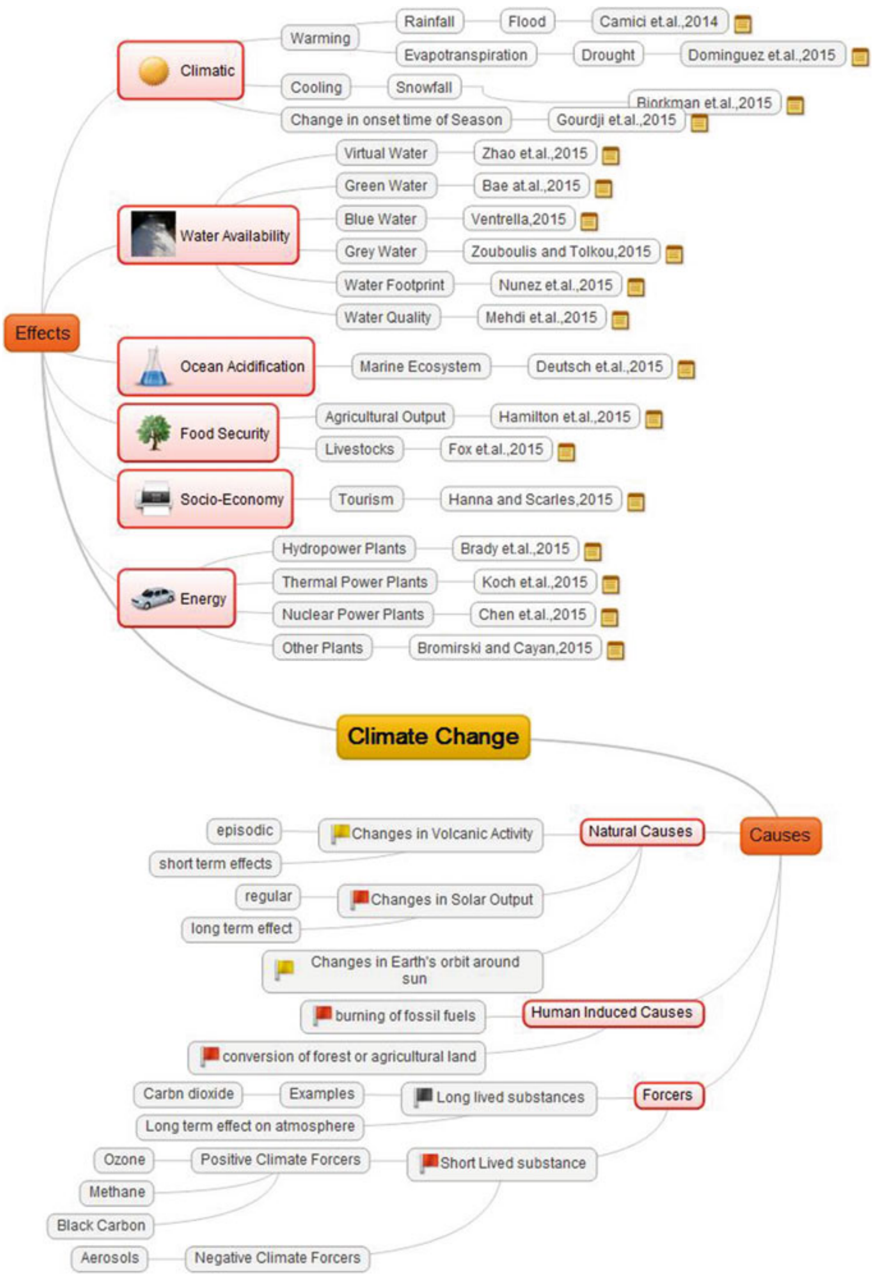

Fig. 2.1 Figure showing the causes and effects of climate change

2.2 Impacts on Hydrological Cycle

The change in climate can induce variations from regular pattern in different hydrological parameters which may yield more number of extreme events like flood or droughts.

Due to the change in the climatic parameters like rainfall, snowfall, evapo-transpirations the availability of water will also change.

The amount of water used in industry (virtual water), agriculture (green water) and the waste water (grey water) generated from such activities will also be impacted.

2.3 Impacts on Watersheds

The change in regular pattern of climate will impact the change in availability of water which will in turn influence the food security, energy production and various other related activities as depicted in Fig. 2.1.

As the rainfall pattern will change, the amount of water stored in the depressions in the catchment will also change. The negative impacts like the reduction of available water due to the change in climate will always degrade the overall status of watersheds.

2.4 IPCC Scenarios

Intergovernmental Panel on Climate Change (IPCC) is an organization which proposes different scenarios of climate change and tries to predict the outcome of that change on different related natural phenomena.

IPCC is headed by Dr. I. E. Guzouli and has won the 2007 Nobel Prize for peace. It proposes scenarios based on population, pollution and land use dynamics and the impact of climate change on these related activities. IPCC has developed 40 different scenarios among the major classes of A1, B1 and A2, B2.

The scenarios are described in detail in the Fig. 2.2.

2.5 Climate Models

The climate models were developed to predict the outcome on climatic parameters due to the scenarios proposed by IPCC. The models divide the entire earth into horizontal and vertical grids of uniform length. The model parameters yield the magnitude of rainfall, surface pressure, wind, humidity and temperature due to the

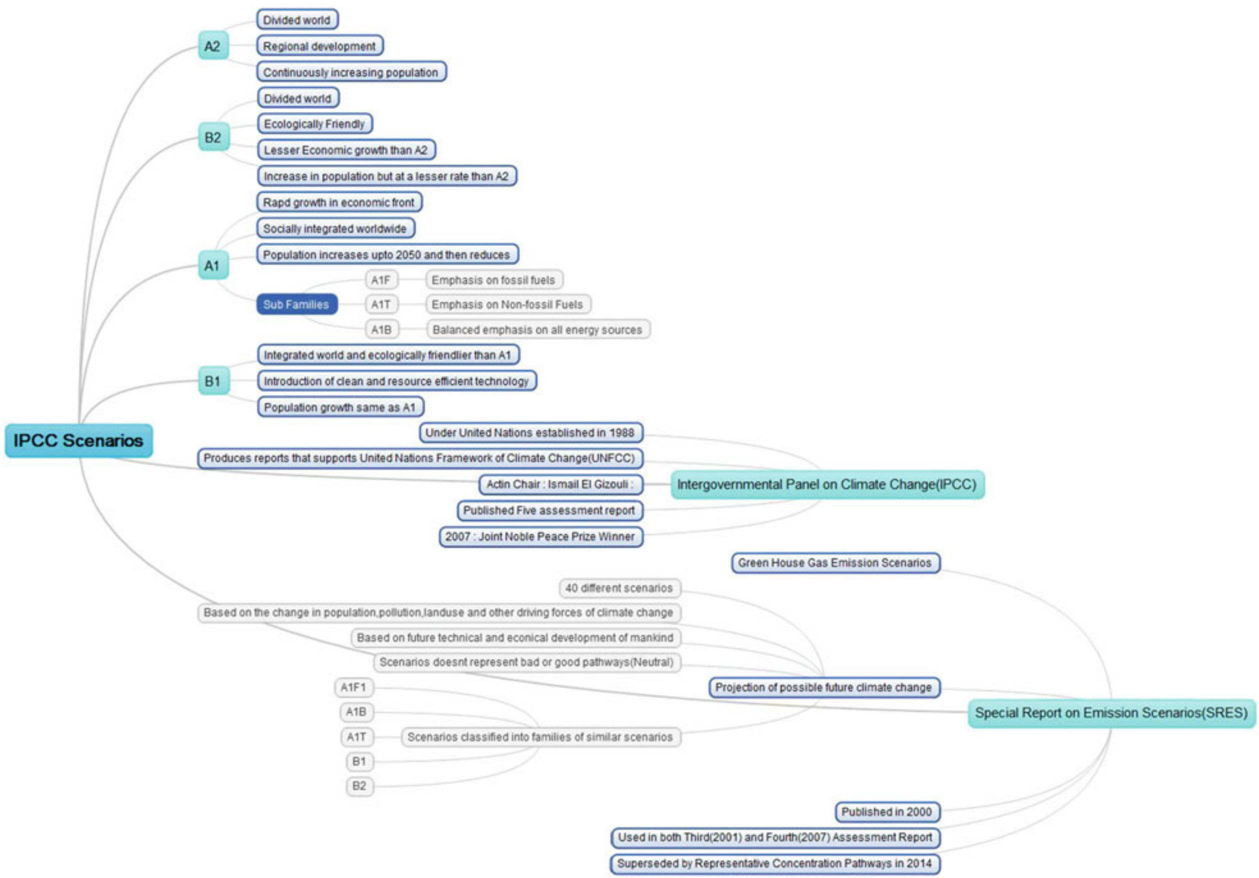

Fig. 2.2 Figure showing the schematics of IPCC scenarios

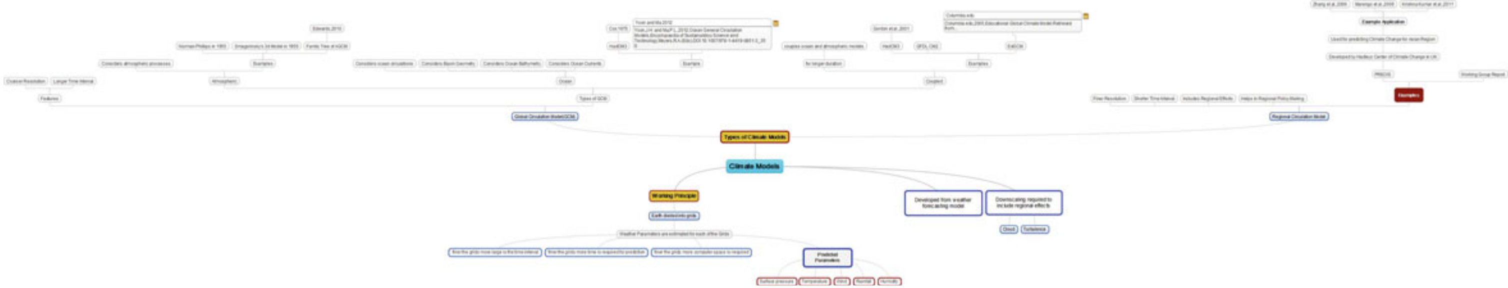

Fig. 2.3 Figure showing different types of climate models

different physical processes which take place in the atmosphere to optimally utilize the radiation received from the sun.

There are two types of model: global (GCM) and regional (RCM) climate models. The global model can be further subdivided into atmospheric (AGCM), oceanic (OGCM) and coupled GCM (AOGCM). As the name suggests, the models consider the interaction of radiation within the atmosphere, ocean and both for AGCM, OGCM and AOGCM, respectively.

The regional climate models include the effects of humidity, cloud cover and presence of mountains and predict an accurate and sharper resolution data of the Earth's climate considering the local influences. Figure 2.3 depicts the development of climate models, the parameters predicted by them and the difference between GCM and RCM.

References

Bae, D. H., Koike, T., Awan, J. A., Lee, M. H., & Sohn, K. H. (2015). Climate change impact assessment on water resources and susceptible zones identification in the Asian monsoon region. *Water Resources Management*, *29*, 1–17.

Bjorkman, A. D., Elmendorf, S. C., Beamish, A. L., Vellend, M., & Henry, G. H. (2015). Contrasting effects of warming and increased snowfall on Arctic tundra plant phenology over the past two decades. *Global Change Biology*.

Brady, J., Patil, S., McNabola, A., Gallagher, J., Coughlan, P., Harris, I., … & Williams, P. (2015, April). An assessment of climate change impacts on micro-hydropower energy recovery in water supply networks. In EGU General Assembly Conference Abstracts (Vol. 17, p. 3922).

Bromirski, P. D., & Cayan, D. R. (2015). Wave power variability and trends across the North Atlantic influenced by decadal climate patterns. *Journal of Geophysical Research: Oceans*.

Camici, S., Brocca, L., Melone, F., & Moramarco, T. (2014). Impact of climate change on flood frequency using different climate models and downscaling approaches. *Journal of Hydrologic Engineering, 19*(8), 04014002.

Chen, Y., Hobbs, B. F., Ellis, J. H., Crowley, C., & Joutz, F. (2015). Impacts of climate change on power sector NO x emissions: A long-run analysis of the US mid-atlantic region. *Energy Policy, 84*, 11–21.

Deutsch, C., Ferrel, A., Seibel, B., Pörtner, H. O., & Huey, R. B. (2015). Climate change tightens a metabolic constraint on marine habitats. *Science, 348*(6239), 1132–1135.

Domínguez, M. T., Sowerby, A., Smith, A. R., Robinson, D. A., Van Baarsel, S., Mills, R. T., & Emmett, B. A. (2015). Sustained impact of drought on wet shrublands mediated by soil physical changes. *Biogeochemistry, 122*(2–3), 151–163.

Fox, N. J., Davidson, R. S., Marion, G., & Hutchings, M. R. (2015). Modelling livestock parasite risk under climate change. *Advances in Animal Biosciences, 6*(01), 32–34.

Gourdji, S., Läderach, P., Valle, A. M., Martinez, C. Z., & Lobell, D. B. (2015). Historical climate trends, deforestation, and maize and bean yields in Nicaragua. *Agricultural and Forest Meteorology, 200*, 270–281.

Hamilton, C. M., Thogmartin, W. E., Radeloff, V. C., Plantinga, A. J., Heglund, P. J., Martinuzzi, S., & Pidgeon, A. M. (2015). Change in agricultural land use constrains adaptation of national wildlife refuges to climate change. *Environmental Conservation, 42*(01), 12–19.

Hanna, P., & Scarles, C. (2015). Climate change, public rhetoric and discursive sensibilities: Implications for tourism.

Koch, H., Vögele, S., Hattermann, F. F., & Huang, S. (2015). The impact of climate change and variability on the generation of electrical power. Meteorologische Zeitschrift.

Mehdi, B., Lehner, B., Gombault, C., Michaud, A., Beaudin, I., Sottile, M. F., & Blondlot, A. (2015). Simulated impacts of climate change and agricultural land use change on surface water quality with and without adaptation management strategies. *Agriculture, Ecosystems & Environment, 213*, 47–60.

Núñez, M., Pfister, S., Vargas, M., & Antón, A. (2015). Spatial and temporal specific characterisation factors for water use impact assessment in Spain. *The International Journal of Life Cycle Assessment, 20*(1), 128–138.

Ventrella, D. (2015). Climate change impact on green and blue water consumptive use for winter durum wheat and tomato cultivated in Southern Italy. FACCE MACSUR Reports, 5.

Zhao, X., Liu, J., Liu, Q., Tillotson, M. R., Guan, D., & Hubacek, K. (2015). Physical and virtual water transfers for regional water stress alleviation in China. *Proceedings of the National Academy of Sciences, 112*(4), 1031–1035.

Zouboulis, A., & Tolkou, A. (2015). Effect of climate change in wastewater treatment plants: Reviewing the problems and solutions. In Managing Water Resources under Climate Uncertainty (pp. 197–220). Springer International Publishing.

Chapter 3
Watershed Vulnerabilities

Abstract Watersheds are important because their status control quantity and quality of water resources. There are different types of watersheds which are classified by shape and size, function, etc. There are many examples of indicators which detect vulnerability of watersheds but none of them are objective, cognitive and consider both time and space scale. The indicators also select the parameters based on their need that is why nearly all the indicators are case-sensitive and cannot be used universally. The present study aims to develop an indicator which does not have these lacunae.

Keywords Watershed · Vulnerability analysis · Indicators

The watershed is defined as the area which denotes the farthest place from which water can reach the water body such as rivers or wetlands. The amount of water that can reach the water body depends along with rainfall, on the geophysical properties, land use and depressions available in the watershed.

The shape, size and slope of the watershed also contributes. Broadly watersheds can be classified based on shape, size and area as depicted in Fig. 3.1 and explained in the next section.

3.1 Types of Watersheds

The watersheds can be divided into micro, small and large based on size; micro, small, mini, sub, macro and river basin by area and square, rectangular, triangular, oval, leaf shaped, polygonal and circular with respect to shape.

3.2 Functions of Watersheds

Watersheds have two major functions, viz., hydrological and ecological as described in the Fig. 3.2.

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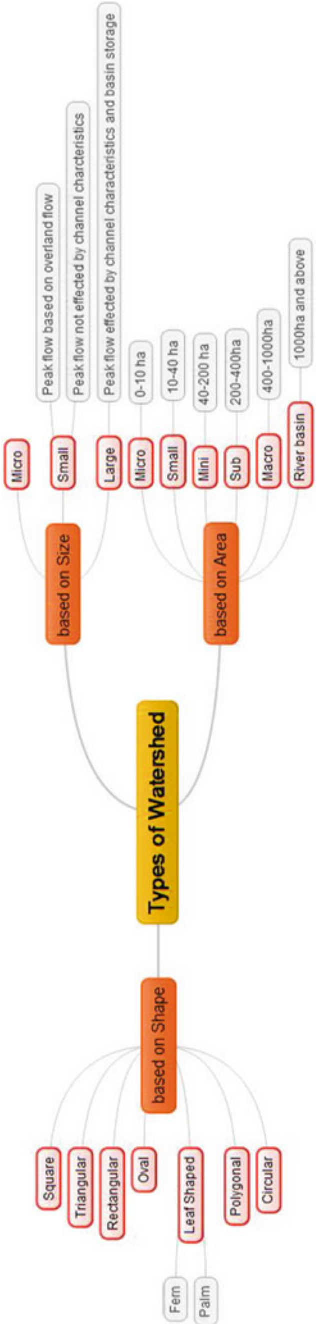

Fig. 3.1 Figure showing the different types of classifications of watersheds

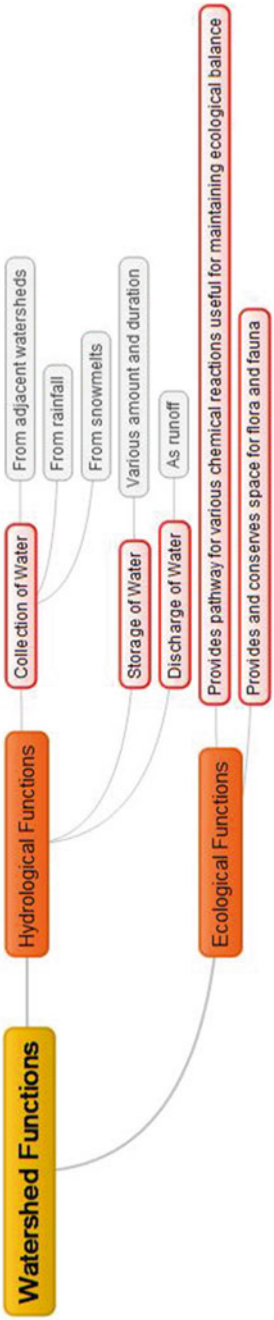

Fig. 3.2 Figure showing the various functions of watershed

3.3 Factors of Vulnerability

There are various factors which can make the watersheds vulnerable or degradable. Factors like amount of impervious area, evapotranspiration and runoff will degrade the watershed if their magnitude increases. Again if the amounts of forest area, rainfall, depressions increase, then the status of watershed will improve.

Actually the quality and quantity of water that a watershed can store will decide the status or health of the watersheds as explained in Fig. 3.3.

Some other morphological factors also influence the status of watersheds as depicted in Fig. 3.4. Any indicator which can adequately represent the status of the watersheds must include the above discussed factors to provide an extensive depiction of the watershed vulnerability.

3.4 Indices Representing Vulnerability

In a paper by Alcamo et al. (2003) audit of global water resources was conducted for both present and future scenarios of climate change. Chaves and Alipaz (2007) and many others proposed indicators for representing the global status of water availability by which the answer to the question raised by Rijsberman (2006) "Water Scarcity: Fact or Fiction?" can be "feasibly" answered.

The indicators or Indices are developed to represent the overall status of watersheds. Indices like water availability index, water poverty index, etc. were developed to estimate the status of the watershed based on various factors which really influences the output or productivity that can be received from the catchment.

Figure 3.5 gives some popular indexes in this regard and also cites in the literature in which the detail description of these media can be found.

A common problems with these indices are:

1. They are uniformly weighted, i.e. given equal importance
2. They are either spatially or temporally varied
3. Most of them do not considered water quality as a parameter
4. All are absolute and subjective in nature.

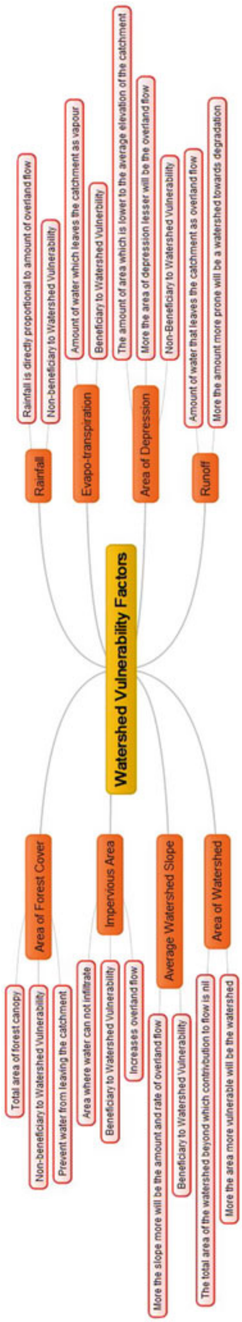

Fig. 3.3 Figure showing different factors which makes watershed vulnerable

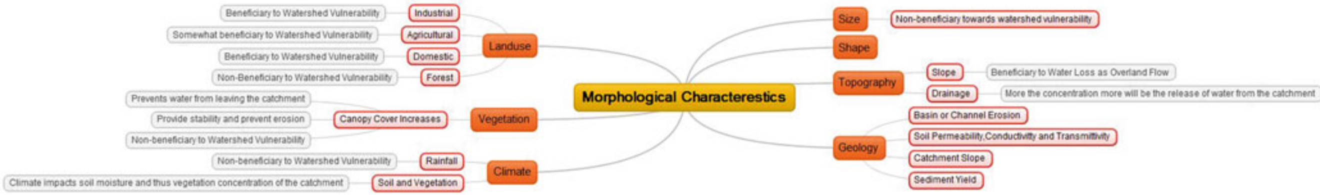

Fig. 3.4 Figure showing different morphological characteristics which influences the status of watersheds

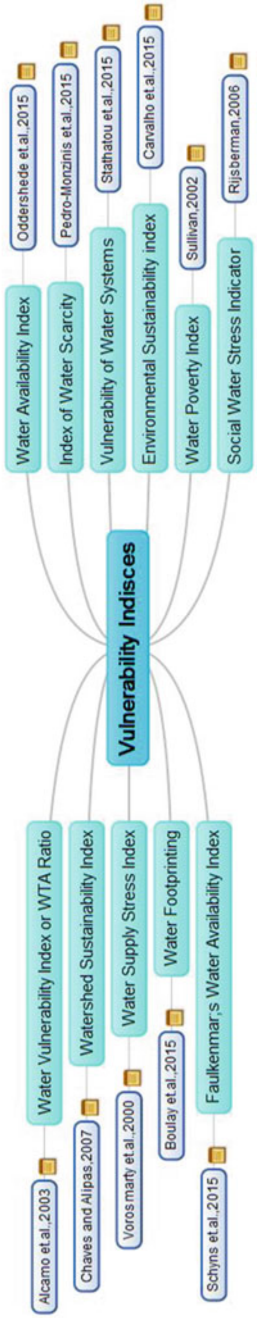

Fig. 3.5 Figure showing different types of indicators used to represent vulnerability of watersheds

References

Alcamo, J., DÖLL, P., Henrichs, T., Kaspar, F., Lehner, B., RÖSCH, T., & Siebert, S. (2003). Global estimates of water withdrawals and availability under current and future “business-as-usual” conditions. *Hydrological Sciences Journal*, *48*(3), 339–348.

Boulay, A. M., Bayart, J. B., Bulle, C., Franceschini, H., Motoshita, M., Muñoz, I., & Margni, M. (2015). Analysis of water use impact assessment methods (part B): applicability for water footprinting and decision making with a laundry case study. *The International Journal of Life Cycle Assessment*, *20*(6), 865–879.

Carvalho, G. R., Ometto, A. R., de Miranda, E. E., & por Satélite, E. M. (2015, February). Sustainability Index for Agribusiness Products Considering Territorial Bases and Life Cycle Thinking. In *Global Conference on Sustainable Product Development and Life Cycle Engineering* (Vol. 4).

Chaves, H. M., & Alipaz, S. (2007). An integrated indicator based on basin hydrology, environment, life, and policy: the watershed sustainability index. *Water Resources Management*, *21*(5), 883–895.

Oddershede, A., Svenning, J. C., & Damgaard, C. (2015). Topographically determined water availability shapes functional patterns of plant communities within and across habitat types. *Plant Ecology*, 1–12.

Pedro-Monzonís, M., Solera, A., Ferrer, J., Estrela, T., & Paredes-Arquiola, J. (2015). A review of water scarcity and drought indexes in water resources planning and management. *Journal of Hydrology*, *527*, 482–493.

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction?. *Agricultural Water Management*, *80*(1), 5–22.

Schyns, J. F., Hoekstra, A. Y., & Booij, M. J. (2015). Review and classification of indicators of green water availability and scarcity. *Hydrology & Earth System Sciences Discussions*, *12*(6).

Stathatou, P. M., Kampragou, E., Grigoropoulou, H., Assimacopoulos, D., Karavitis, C., Porto, M. F. A., & Reyna, S. (2015). Vulnerability of water systems: a comprehensive framework for its assessment and identification of adaptation strategies. *Desalination and Water Treatment*, (ahead-of-print), 1–13.

Sullivan, C. (2002). Calculating a water poverty index. *World Development*, *30*(7), 1195–1210.

Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: vulnerability from climate change and population growth. *Science*, *289*(5477), 284–288.

Chapter 4
Methodology

Abstract The proposed indicator was developed with the help of multi-criteria decision-making method analytical hierarchy process to make the index objective and artificial neural network variant group method of data handling to include cognitivity into the indicator. The parameter of the indicator was collected with respect to its citation frequency in the published literature. In the MCDM step, the input parameters were selected and rated based on different criteria. The weights of importance or priority value as derived from the MCDM method was used in the weight function to constitute the indicator. The ANN model was developed to provide cognitivity as well as to make it platform independent and also to hide the weights of importance of the parameters so that a non-preferential decision-making can be conducted. The output from climate models was used to estimate the climatic vulnerability of the selected river basins by the developed indicator.

Keywords Weight function · MCDM-ANN · Indicator · Climatic vulnerability

The present investigation utilized AHP to find the priority value of the parameters and ANN tool to predict the indicators.

The proposed method comprises of two steps:

1. Application of MCDM method to determine the priority values of the selected factors
2. Application of ANN to develop a model which can estimate the index for different scenarios.

Once the model is developed it was applied in three selected study areas to find the intensity of climatic vulnerabilities on the watershed under normal as well as changed climate scenarios.

In any MCDM methods, the first step involves the selection of criteria followed by selection of alternatives. Then, the method of aggregation is selected which ultimately yielded the weights of importance for the selected parameters.

In the present study:

1. Climatic Effect
2. Urbanization Effect
3. Socio-Economical Effect

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Was taken as the criteria with respect to which the selected factors will be compared to find the relative weights of the parameters.

The selected factors of the decision-making study were chosen after a thorough metastatic analysis. The considered factors are as follows:

1. Rainfall (P) (B)
2. Evapo-transpiration (ET) (NB)
3. Runoff (Q) (NB)
4. Area of Depressions (D) (B)
5. Area of Forest Cover (F) (B)
6. Impervious Area (I) (NB)
7. Quality of Water (WQI) (B)
8. Average Slope of the Watershed (S) (NB)
9. Area of the Watershed (A) (B).

The B and NB indicated in the first bracket depict that whether the parameters are directly proportional with the retention capacity of the watershed or inversely proportional to the objective of the study.

That means if the index is made directly proportional to the factors which are indicated as B and inversely proportional to the parameters which are indicated as NB, then retention capacity of watersheds or availability of water in the water sheds will be directly proportional with the index.

The inverse of the index will be directly proportional to the vulnerability to change in climatic pattern.

That is why the index is developed by the weighted sum of B factors divided by the weighted sum of the NB factors.

So, more the value of the index, more will be the capacity of retention of the watershed and less will be the vulnerability of the watershed towards the climatic abnormality.

The temporal variability of the factors are introduced by taking the peak value of a day, week, month, half-yearly and yearly variation of the beneficial parameters (B) and crest value of the non-beneficial parameters (NB).

4.1 Application of Analytical Hierarchy Process

4.1.1 Selection of Criteria

The criteria of the present decision making objective was taken as the Climatic Effect, Urbanization Effect and Financial Effect.

For every criterion, the parameters were scored and according to the score they are ranked in an ascending manner where the most important parameters gets the top and least important parameter finds the last position.

4.1.1.1 Estimation of Scores with Respect to Climatic Effect

Various literatures, books, reports, experts and common people are consulted before taking a decision about the score of a parameter with respect to the climatic effects. The score of a parameter with respect to the climatic effect was given in the following manner

A. Documents and people are consulted to find an answer to the question that whether this parameter will face any change due to the change in climatic effects.
B. Whenever the answer is yes, it is counted.
C. Now, if total number of literatures including books and reports are L and experts and common people consulted are E and C, respectively, then the score of a parameter for climatic effect is calculated by Eq. 4.1.

$$C = \{w_1 \times (l/L) + w_2 \times (e/E) + w_3 \times (c/C)\}/\{w_1 + w_2 + w_3\} \tag{4.1}$$

where $w_1 > w_2 > w_3$ and all three are real but fractional number summation of which is 1. The l, e and c depict the number of yes found from literatures, experts and common people.

4.1.1.2 Estimation of Scores with Respect to Urbanization Effect

The effect of urbanization on the selected factors was estimated by reviewing the related literatures and concerned experts and common people. In this case also, the same question was asked only instead of climatic effect the people or documents are consulted about the urbanization effects. The procedures are also similar to the method for determination of climatic effect.

A. Documents and people are consulted to find an answer to the question that whether this parameter will face any change due to the change in the density of urban population.
B. Whenever the answer is yes it is counted.
C. Now, if total number of literatures including books and reports are L and experts and common people consulted are E and C, respectively, then the score of a parameter for climatic effect is calculated by Eq. 4.2.

$$U = \{m_1 \times (l/L) + m_2 \times (e/E) + m_3 \times (c/C)\}/\{m_1 + m_2 + m_3\} \tag{4.2}$$

where $m_1 > m_2 > m_3$ and all three are real but fractional number summation of which is 1. The l, e and c depict the number of yes found from literatures, experts and common people.

4.1.1.3 Estimation of Scores with Respect to Financial Effect

The change in the parameters affecting the watershed retention capacity may also affect the financial potential from the concerned basin. The change in parameters can cause hazards, life-loss or may induce severe liabilities for the local inhabitants resulting into loss of financial status. The experts and common people are also discussed regarding the financial impact that can be caused by the change in the selected factors.

A. Various literatures, experts and concerned people are consulted to find the answer to the same question only instead of climatic or urbanization effect they are asked about the financial impact that can be caused by the said parameters.
B. All the yes are counted.
C. Now, if total number of literatures including books and reports are L and experts and common people consulted are E and C, respectively, then the score of a parameter for climatic effect is calculated by Eq. 4.3.

$$F = \{f_1 \times (l/L) + f_2 \times (e/E) + f_3 \times (c/C)\}/\{f_1 + f_2 + f_3\} \tag{4.3}$$

where $f_1 > f_2 > f_3$ and all three are real but fractional number summation of which is 1. The l, e and c depict the number of yes found from literatures, experts and common people.

Now the values of w, m and f may or may not be equal to each other.

The importances of the criteria are considered based on the objective of the present study. As the study mainly deals with the climatic impact on watersheds the climatic effect followed by urbanization effect was given the higher importance than the financial effects.

4.1.2 Selection of Alternatives

After a thorough review of the literatures the top eight most cited parameters which can affect the availability of water in watersheds are selected as factors or alternatives which will be compared with each other based on their importance as per the climatic, urbanization and financial effects.

4.1.3 Determination of Weights by AHP

As a first step in AHP the criteria are compared with each other to find the importance of each criterion over the other. The importance is represented by the weights where more the value of the weights more will be the importance of the criteria.

The criteria pair-wise comparison matrix is thus a 3 × 3 matrix for the present study.

After the importances of criteria are estimated the alternatives are compared with each other with respect to each of the criteria. Thus the alternative pair-wise matrix is found to be a 9 × 9 matrix.

As the alternatives will be compared with each other based on each of the criteria there will be three alternative matrixes.

Ultimately the weights of criteria will be multiplied with the weights of alternatives for those criteria to find the overall weights or priority value of the factor which will be directly in proportional to the importance of the alternatives with respect to the other considered factors.

So a 1 × 3 matrix will be multiplied with a 9 × 3 matrix to determine a 9 × 1 matrix which will give the priority values of all the considered factors.

4.2 Development of Vulnerability Index

The vulnerability index was developed with the help of Eq. 4.4.

$$\sum(w_m \times \mathrm{B}_m)/\sum(w_n \times \mathrm{NB}_n) \tag{4.4}$$

where m and n are the no. of beneficiary (B) and non-beneficiary (NB) factors and w is the weight or priority value of the parameters as determined from the MCDM method.

The index is made inversely proportional to vulnerability of watershed with respect to availability of water by putting the parameters which enhances the water retentivity of the watersheds as numerator and assigning the parameters which are inversely proportional to water availability in the denominator.

4.3 Development of the Artificial Neural Network Model

An ANN model was developed with nine inputs and one output. The number of hidden layers was determined by heuristic search algorithm and the type of activation function for the input and hidden and hidden and output layers was selected as Logistic.

Various training algorithms were applied in a combinatorial approach to find the optimal weights of the input-hidden and hidden-output connections.

The architecture of the neural network was polymorphic and feed-forward in nature.

The residual error along with coefficient of determination was used to analyze the fitness of the network.

4.4 Ranking of Selected Watersheds

4.4.1 Data Collection from Climatic Model

The data for the three selected study area for the future climatic scenarios were collected from the climate models. The data for two scenarios were collected: IPCC A2 and B2 scenarios.

- A1 storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
- A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
- B1 storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- B2 storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

4.4.2 Prediction from ANN Model

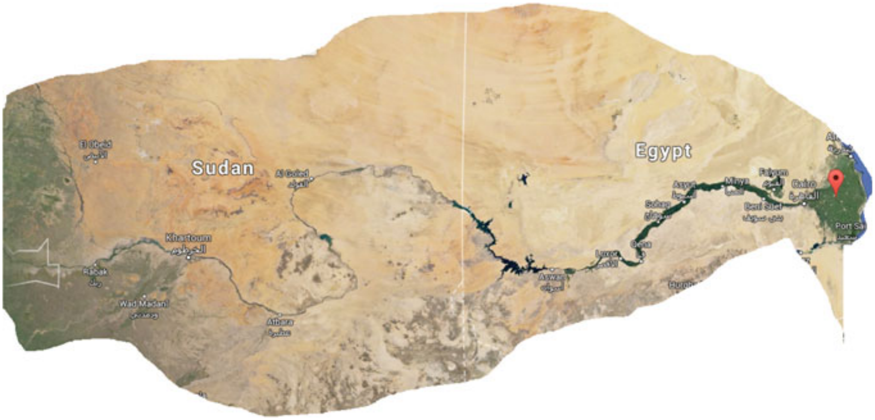
The values of the input parameters for the two scenarios in three time slabs were normalized and fed to the ANN model for which six different index values were predicted by the model.

As the index is directly proportional to the water availability but inversely proportional to the vulnerability of the watersheds towards climatic changes more the value of the index more will be retention capacity and less will be the climatic vulnerability.

4.4.3 *Study Areas*

Location

River Nile (*Source* Google Map, 2014)



Nile River, Arabic Baḥr Al-Nīl or Nahr Al-Nīl River, the Father of African Rivers and is the longest river in the world. It rises south of the Equator and flows northward through northeastern Africa to drain into the Mediterranean Sea. It has a length of about 4,132 miles (6,650 km) and drains an area estimated at 1,293,000 miles^2 (3,349,000 km^2). Its basin includes parts of Tanzania, Burundi, Rwanda, the Democratic Republic of the Congo, Kenya, Uganda, South Sudan, Ethiopia, Sudan, and the cultivated part of Egypt. Its most distant source is the Kagera River in Burundi.

The Nile is formed by three principal streams: the Blue Nile (Arabic: Al-Baḥr Al-Azraq; Amharic: Abay) and the Atbara (Arabic: Nahr ʿAṭbarah), which flow from the highlands of Ethiopia, and the White Nile (Arabic: Al-Baḥr Al-Abyad), the headstreams of which flow into Lakes Victoria and Albert.

The name Nile is derived from the Greek Neilos (Latin: Nilus), which probably originated from the Semitic root naḥal, meaning a valley or a river valley and hence, by an extension of the meaning, a river. The fact that the Nile—unlike other great rivers known to them—flowed from the south northward and was in flood at the warmest time of the year was an unsolved mystery to the ancient Egyptians and Greeks. The ancient Egyptians called the river Ar or Aur (Coptic: Iaro), “Black”, in allusion to the colour of the sediments carried by the river when it is in flood. Nile mud is black enough to have given the land itself its oldest name, Kem or Kemi, which also means “black” and signifies darkness. In The Odyssey, the epic poem written by the Greek poet Homer (seventh century bce), Aigyptos is the name of the Nile (masculine) as well as the country of Egypt (feminine) through which it flows.

The Nile in Egypt and Sudan is now called Al-Nīl, Al-Baḥr, and Baḥr Al-Nīl or Nahr Al-Nīl.

River Amazon (*Source* Google Earth, 2014)

Amazon River, Portuguese Rio Amazonas, Spanish Río Amazonas, also called Río Marañón and Rio Solimões, the greatest river of South America and the largest drainage system in the world in terms of the volume of its flow and the area of its basin. The total length of the river—as measured from the headwaters of the Ucayali-Apurímac river system in southern Peru—is at least 4,000 miles (6,400 km), which makes it slightly shorter than the Nile River but still the equivalent of the distance from New York City to Rome. Its westernmost source is high in the Andes Mountains, within 100 miles (160 km) of the Pacific Ocean, and its mouth is in the Atlantic Ocean, on the northeastern coast of Brazil. However, both the length of the Amazon and its ultimate source has been subjects of debate since the mid-twentieth century, and there are those who claim that the Amazon is actually longer than the Nile.

The Amazon basin is a great structural depression, a subsidence trough that has been filling with immense quantities of sediment of Cenozoic age (i.e. dating from about the past 65 million years). This depression, which flares out to its greatest dimension in the Amazon's upper reaches, lies between two old and relatively low crystalline plateaus, the rugged Guiana Highlands to the north and the lower Brazilian Highlands (lying somewhat farther from the main river) to the south. The Amazon basin was occupied by a great freshwater sea during the Pliocene Epoch (5.3–2.6 million years ago). Sometime, during the Pleistocene Epoch (about 2,600,000–11,700 years ago), an outlet to the Atlantic was established, and the great river and its tributaries became deeply entrenched in the former Pliocene seafloor.

The modern Amazon and its tributaries occupy a vast system of drowned valleys that have been filled with alluvium. With the rise in sea level that followed the melting of the Pleistocene glaciers, the steep-sided canyons that had been eroded into the Pliocene surface during the period of lower sea levels were gradually flooded. In the upper part of the basin—in eastern Colombia, Ecuador, Peru, and Bolivia—more recent outwash from the Andes has covered many of the older surfaces.

River Yangtze (*Source* Google Earth, 2014)

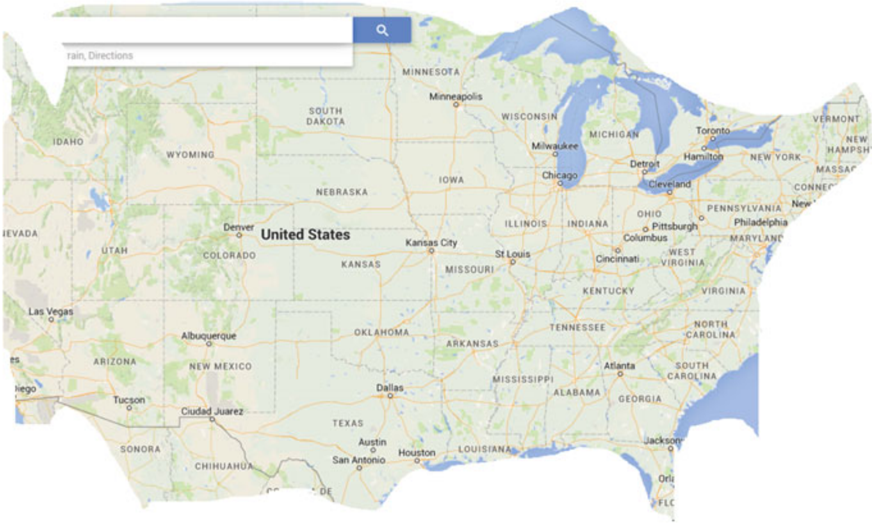
Winding about 3,964 miles, Yangtze River is the largest in China and the third largest in the world after the Nile in Africa and the Amazon in South America. Originating from the Tanggula Range in Qinghai Province in western China, it traverses eleven provinces and cities from west to east, including Qinghai, Tibet, Sichuan, Yunnan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Shanghai. Finally, it pours into the East China Sea at Shanghai.

Acting as the largest water system in China, Yangtze River is historically, economically and culturally important to the country. It has numerous tributaries including Min River, Han River, Jialing River, Gan River and Huangpu River, etc. The Three Gorges Dam on the river is the largest dam project and hydro-electric power station in the world. Generally, people consider the river a dividing line between North China and South China. Areas to the north and the south of the river have many differences in climate, scenery, economics, culture and folk customs.

Yangtze River is the largest in China and the third longest in the world, next to the Nile in Africa and the Amazon in South America. Rising in Tanggula Mountain, it flows eastwards and pours itself into the East China Sea. Measuring about 6,380 km (3,964 miles), it mainly runs across Qinghai-Tibet Plateau, Sichuan, Yunnan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Shanghai from west to east.

Yangtze River Basin is a big granary of China. The grain it produces covers a half of the whole nation, of which the rice accounts for 70 % in the total. Other crops such as cotton, barley, wheat, maize and bean are also produced in the area. Besides, it is the most prosperous and densely populated area in the country. The important cities with a population of over one million such as Shanghai, Nanjing, Wuhan, Chongqing and Chengdu are located in the area. Same as the Yellow River, Yangtze River is also the cradle of Chinese civilization. It is endowed with long history and abundant cultural relics.

River Mississippi (*Source* Google Map, 2014)



The Mississippi River is one of the world's major river systems in size, habitat diversity and biological productivity. It is the third longest river in North America, flowing 2,350 miles from its source at Lake Itasca through the centre of the continental United States to the Gulf of Mexico.

When compared to other world rivers, the Mississippi-Missouri River combination ranks fourth in length (3,710 miles/5,970 km) following the Nile (4,160 miles/6,693 km), the Amazon (4,000 miles/6,436 km), and the Yangtze Rivers (3,964 miles/6,378 km). The reported length of a river may increase or decrease as deposition or erosion occurs at its delta, or as meanders are created or cutoff. As a result, different lengths may be reported depending upon the year or measurement method.

Length

For reasons mentioned above there are competing claims as to the Mississippi's length. The staff of Itasca State Park at the Mississippi's headwaters says that the river is 2,552 miles long. The US Geologic Survey has published a number of 2,300 miles, the EPA says it is 2,320 miles long, and the Mississippi National River and Recreation Area suggests the river's length is 2,350 miles.

Width

At Lake Itasca, the river is between 20 and 30 ft wide, the narrowest stretch for its entire length. The widest part of the Mississippi can be found at Lake Winnibigoshish near Bena, MN, where it is wider than 11 miles. The widest navigable part of the Mississippi is Lake Pepin, where it is approximately 2 miles wide.

Speed

At the headwaters of the Mississippi, the average surface speed of the water is near 1.2 miles/h—roughly one-third as fast as people walk. At New Orleans the river flows 3 miles/h on average.

The Mississippi River watershed is the fourth largest in the world, extending from the Allegheny Mountains in the east to the Rocky Mountains in the west. The watershed includes all or parts of 31 states and 2 Canadian Provinces. The watershed measures approximately 1.2 million miles^2, covering about 40 % of the lower 48 states.

River Yenisei (*Source* Google Map, 2014)

Yenisey River, also spelled Yenisei or Enisei, Evenk Ioanesi ("Great River"), river of central Russia, one of the longest rivers in Asia. The world's sixth largest river in terms of discharge, the Yenisey runs from south to north across the great expanse of central Siberia. It traverses a vast region of strikingly varied landscapes where ancient peoples and customs as well as an enormous economic infrastructure are found.

The river begins at the city of Kyzyl in the republic of Tyva (Tuva), Russia, at the confluence of its headstreams—the Great (Bolshoy) Yenisey, or By-Khem, which rises on the Eastern Sayan Mountains of Tyva, and the Little (Maly) Yenisey, or Ka-Khem, which rises in the Darhadïn Bowl of Mongolia. From the confluence the Yenisey River runs for 2,167 miles (3,487 km), mainly along the border between eastern and western Siberia, before emptying into the icy Kara Sea. If the Great Yenisey is considered the source, then the river is 2,540 miles (4,090 km) long. The headwaters of the Selenga (Selenge) River, which rise in western Mongolia and flow through Lake Baikal (the world's deepest freshwater lake) into the Angara tributary of the Yenisey, may, however, be considered the river's ultimate source. With the inclusion of the Selenga, the Yenisey is 3,442 miles (5,539 km) long and drains a basin that, at 996,000 miles^2 (2,580,000 km^2), is the seventh largest in the world. The system within Siberia's boundaries comprises some 20,000 tributary or sub-tributary streams, with an aggregate length of approximately 550,000 miles (885,000 km). All of the major tributaries of the Yenisey flow from the Central Siberian Plateau to its east, a region constituting 80 % of the basin area.

River Ganges (*Source* Prokerala, 2015)

The Ganges River, also called Ganga, is a river located in northern India that flows toward the border with Bangladesh (map). It is the longest river in India and flows for around 1,569 miles (2,525 km) from the Himalayan Mountains to the Bay of Bengal. The river has the second greatest water discharge in the world and its basin is the most heavily populated in the world with over 400 million people living in the basin.

The Ganges River is extremely important to the people of India as most of the people living on its banks use it for daily needs such as bathing and fishing. It is also significant to Hindus as they consider it their most sacred river.

Course of the Ganges River

The headwaters of the Ganges River begin high in the Himalayan Mountains where the Bhagirathi River flows out of the Gangotri Glacier in India's Uttarakhand

Table 4.1 Table showing the present status of the selected river basin with respect to the considered parameters

Rivers name	P (mm/year)	ET (mm/km^2)	Q (m^3/s)	D (Rank)	F (Rank)	I (Rank)	WQI (Rank)	S (Rank)	A (km^2)
Nile	1520	307	5100	6	6	1	3	1	3,254,555
Amazon	1500	1000	21,9000	1	1	6	2	4	7,050,000
Yangtze	850	650	31,900	3	2	5	5	6	1,800,000
Mississippi	900	500	16,200	2	3	3	4	2	2,980,000
Yenisei	1190	275	19,600	4	4	4	1	5	2,580,000
Ganges	2290	475	12,037	5	5	2	6	3	907,000

state. The glacier sits at an elevation of 12,769 ft (3,892 m). The Ganges River proper begins farther downstream where the Bhagirathi and Alaknanda rivers join. As the Ganges flows out of the Himalayas it creates a narrow, rugged canyon.

The Ganges River emerges from the Himalayas at the town of Rishikesh where it begins to flow onto the Indo-Gangetic Plain. This area, also called the North Indian River Plain, is a very large, relatively flat, fertile plain that makes up most of the northern and eastern parts of India as well as parts of Pakistan, Nepal and Bangladesh. In addition to entering the Indo-Gangetic Plain at this area, part of the Ganges River is also diverted toward the Ganges Canal for irrigation in the Uttar Pradesh state.

As the Ganges River then flows farther downstream it changes its direction several times and is joined by many other tributary rivers such as the Ramganga, Tamsa and Gandaki rivers to name a few. There are also several cities and towns that the Ganges River passes through on its way downstream. Some of these include Chunar, Kolkata, Mirzapur, and Varanasi. Many Hindus visit the Ganges River in Varanasi as that city is considered the holiest of cities. As such, the city's culture is also closely tied into the river as it is the most sacred river in Hinduism.

Once the Ganges River flows out of India and into Bangladesh its main branch is known as the Padma River. The Padma River is joined downstream by large rivers like the Jamuna and Meghna rivers. After joining the Meghna it takes on that name before flowing into the Bay of Bengal. Prior to entering the Bay of Bengal however, the river creates the world's largest delta, Ganges Delta. This region is a highly fertile sediment laden area that covers 23,000 miles^2 (59,000 km^2).

It should be noted that the course of the Ganges River described in the above paragraphs is a general description of the river's route from its source where the Bhagirathi and Alaknanda rivers join to its outlet at the Bay of Bengal. The Ganges has a very complicated hydrology and there are several different descriptions of its overall length and the size of its drainage basin based on what tributary rivers are included. The most widely accepted length of the Ganges River is 1,569 miles (2,525 km) and its drainage basin is estimated to be about 416,990 miles^2 (1,080,000 km^2) (Table 4.1).

References

Google Map (2014) Retrieved from Google Map on 11 December 2014.
Google Earth (2014) Retrieved from Google Earth on 11 December 2014.
Google Earth (2014) Retrieved from Google Earth on 11 December 2014.
Google Map (2014) Retrieved from Google Map on 11 December 2014.
Google Map (2014) Retrieved from Google Map on 11th December 2014.
Prokerala (2015) Retrieved from http://www.prokerala.com on 15th November 2015.

Chapter 5
Results and Discussions

Abstract The study results identified impervious area and area of the watershed to be the most and the least important parameter with respect to the objective and based on different criteria like climatic, financial and urbanization impacts. The accuracy of ANN model was found to be more than 99 %. The results from the sensitivity analysis depict that the sensitivity and weight of importance of the parameter are totally coherent. The Nile River Basin and Yenisei River Basin were found to be the most and the least vulnerable watersheds, but in face of climate change River Mississippi in the USA becomes the most vulnerable in B2 scenario and the least vulnerable in A2 scenario.

Keywords Sensitivity · River basin · Most important · Least important

5.1 Results

The results from the AHP analysis show that impervious area is the most important factor for depiction of watershed vulnerability through an index followed by rainfall and area of forest cover.

5.1.1 Result from AHP Application

See Tables 5.1, 5.2, 5.3, 5.4 and 5.5.

U. Roy and M. Majumder, *Vulnerability of Watersheds to Climate Change Assessed by Neural Network and Analytical Hierarchy Process*, SpringerBriefs in Water Science and Technology, DOI 10.1007/978-981-287-344-6_5

Table 5.1 Table showing the rank of the criteria with respect to their importance in determination of climatic vulnerability of watersheds

Criteria	Rank of importance
Climatic impact	1
Urbanization impact	2
Financial impact	3

Table 5.2 Table showing the rank of the parameters as per their importance with respect to climatic impact

Parameters	Rank of Importance
Rainfall (B)	1
Evapo-transpiration (NB)	2
Runoff (NB)	3
Area of depressions (B)	7
Area of forest cover (B)	4
Impervious area (NB)	6
Quality of water (B)	5
Average slope of the watershed (NB)	8
Area of the watershed (B)	9

Table 5.3 Table showing the rank of the parameters as per their importance with respect to urbanization impact

Parameters	Rank of importance
Rainfall (B)	9
Evapo-transpiration (NB)	8
Runoff (NB)	7
Area of depressions (B)	3
Area of forest cover (B)	2
Impervious area (NB)	1
Quality of water (B)	6
Average slope of the watershed (NB)	4
Area of the watershed (B)	5

Table 5.4 Table showing the rank of the parameters as per their importance with respect to financial impact

Parameters	Rank of importance
Rainfall (B)	1
Evapo-transpiration (NB)	3
Runoff (NB)	2
Area of depressions (B)	7
Area of forest cover (B)	6
Impervious area (NB)	4
Quality of water (B)	5
Average slope of the watershed (NB)	9
Area of the watershed (B)	8

Table 5.5 Table showing the priority values of the factors with respect to AHP method

Parameters	Priority value or weights of importance	Rank as per their importance
Rainfall (B)	0.333	2
Evapo-transpiration (NB)	0.162	5
Runoff (NB)	0.178	4
Area of depressions (B)	0.159	6
Area of forest cover (B)	0.236	3
Impervious area (NB)	0.417	1
Quality of water (B)	0.118	8
Average slope of the watershed (NB)	0.123	7
Area of the watershed (B)	0.106	9

5.1.1.1 Vulnerability Index

If,

$$\begin{pmatrix} 0.333 & 0 & 0 & 0 & 0 \\ 0 & 0.159 & 0 & 0 & 0 \\ 0 & 0 & 0.236 & 0 & 0 \\ 0 & 0 & 0 & 0.118 & 0 \\ 0 & 0 & 0 & 0 & 0.106 \end{pmatrix} \times \begin{pmatrix} \mathrm{P} \\ \mathrm{D} \\ \mathrm{F} \\ \mathrm{WQI} \\ \mathrm{A} \end{pmatrix} = [\mathrm{B}]$$

$$\begin{pmatrix} 0.162 & 0 & 0 & 0 \\ 0 & 0.178 & 0 & 0 \\ 0 & 0 & 0.417 & 0 \\ 0 & 0 & 0 & 0.123 \end{pmatrix} \times \begin{pmatrix} \mathrm{ET} \\ \mathrm{Q} \\ \mathrm{I} \\ \mathrm{S} \end{pmatrix} = [\mathrm{NB}]$$

Then,

$$\mathrm{V} = [\mathrm{B}]/[\mathrm{NB}]. \tag{5.1}$$

5.1.2 *Application of ANN*

The ANN model was developed with the help of 9 inputs and 1 output. As per the model results optimal topology was found with 8 hidden layers.

5.1.2.1 Data Analysis

The training of the model was performed with a set of 498 data rows generated from the randomization within the minimum and maximum values of the parameters after normalization (Figs. 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6).

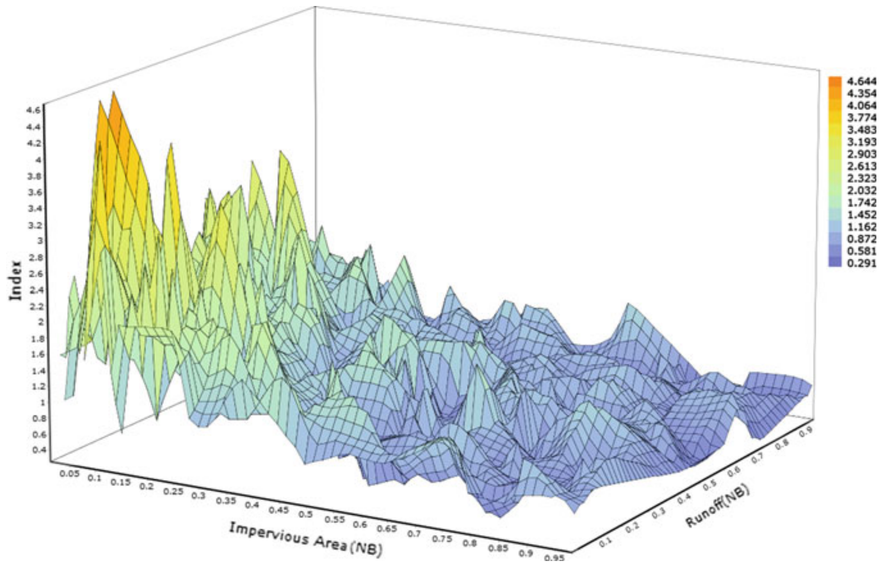


Fig. 5.1 Figure showing the response of vulnerability index with respect to impervious area and runoff

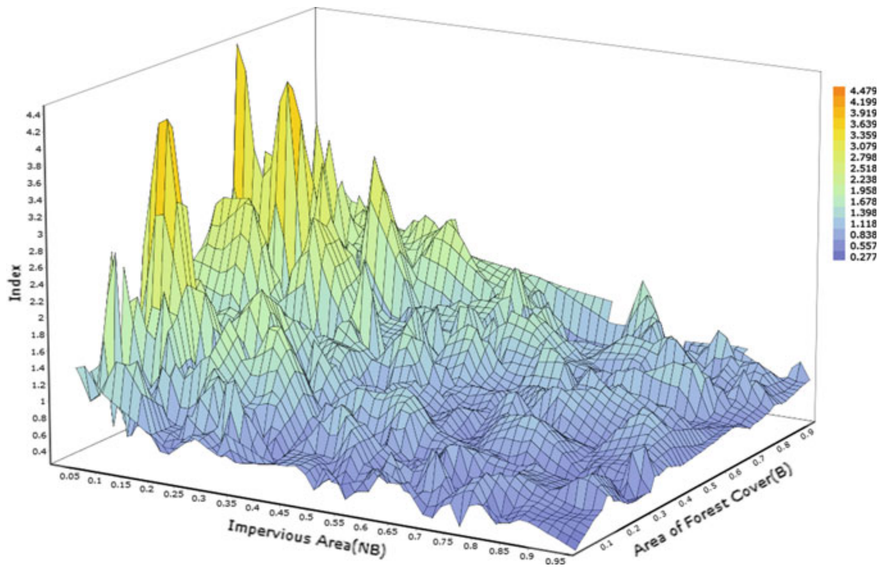


Fig. 5.2 Figure showing the response of vulnerability index with respect to impervious area and area of forest cover

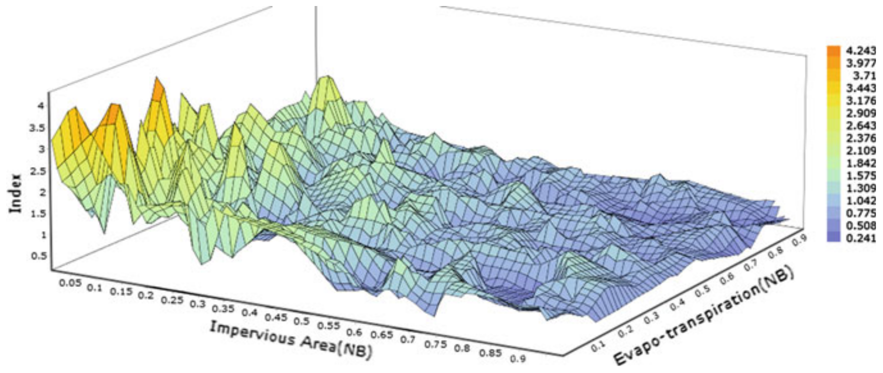


Fig. 5.3 Figure showing the response of vulnerability index with respect to impervious area and evapo-transpiration

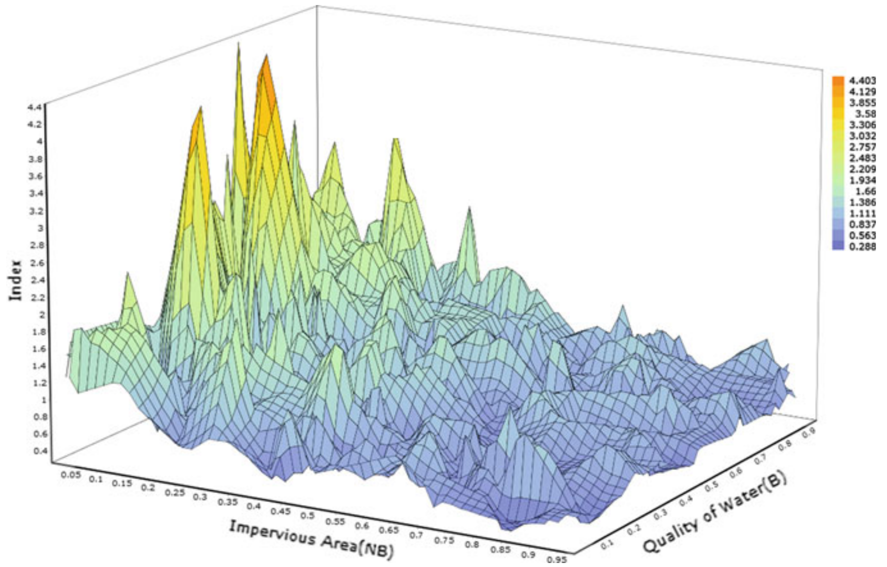


Fig. 5.4 Figure showing the variation of index with respect to the impervious area and quality of water as per the training dataset

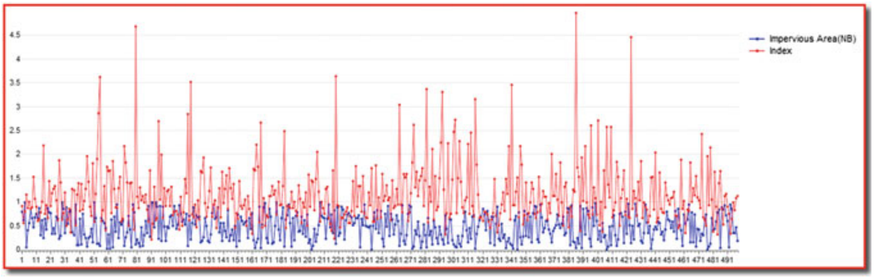


Fig. 5.5 Figure showing the variation of index value with the most important factor: impervious area of the watershed

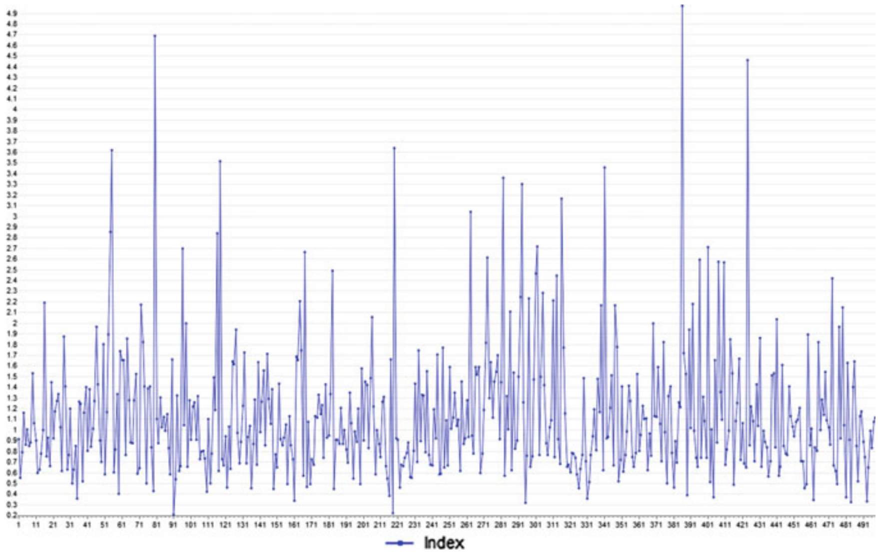
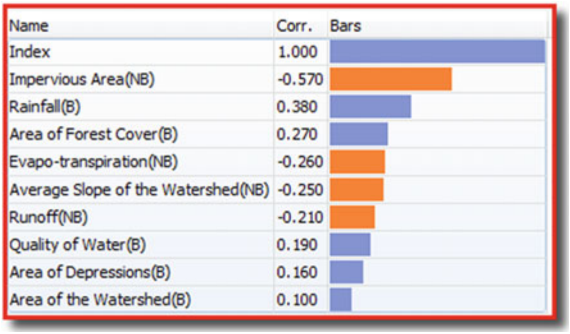


Fig. 5.6 Figure showing the actual index value as per the training data set

	Rainfall(B)	Evapo-tra...	Runoff(NB)	Area of D...	Area of F...	Imperviou...	Quality of...	Average ...	Area of th...	Index
Numeric values	498	498	498	498	498	498	498	498	498	498
Text values	0	0	0	0	0	0	0	0	0	0
Missing values	0	0	0	0	0	0	0	0	0	0
Unique values	498	498	498	498	498	498	498	498	498	498
Zero values	0	0	0	0	0	0	0	0	0	0
Most frequent										
Min. value	0.00147	0.001417	0.0004149	0.0001458	0.001618	0.0003854	0.003817	0.001457	0.0001512	0.2076
Max. value	0.995	0.9896	0.9983	0.999	0.9976	0.9933	0.9991	0.9995	0.9986	4.969
Median	0.4816	0.5185	0.4826	0.4951	0.4949	0.4756	0.5331	0.5405	0.5104	0.9956
Mean value	0.4895	0.5118	0.4942	0.4926	0.4827	0.4722	0.5231	0.5224	0.4945	1.149
Std. deviation	0.2872	0.2867	0.2995	0.2805	0.2867	0.2797	0.2954	0.2917	0.2916	0.6359
2σ outliers	0	0	0	0	0	0	0	0	0	25
3σ outliers	0	0	0	0	0	0	0	0	0	10
4σ outliers	0	0	0	0	0	0	0	0	0	3

Plate Showing the Descriptive Statistics of the Input Factors for the Training Data.



Name	Corr.	Bars
Index	1.000	
Impervious Area(NB)	-0.570	
Rainfall(B)	0.380	
Area of Forest Cover(B)	0.270	
Evapo-transpiration(NB)	-0.260	
Average Slope of the Watershed(NB)	-0.250	
Runoff(NB)	-0.210	
Quality of Water(B)	0.190	
Area of Depressions(B)	0.160	
Area of the Watershed(B)	0.100	

Plate Showing the Sensitivity of Each Input Factor with respect to the Output based on the Training Data Set.

Model Equation:

Y1 = 0.014088 + N478 * N2 * 0.0171273 + N2 * 0.965655
N2 = −0.0381994 + N529 * 0.0421562 + N3 * 0.991351
N3 = −0.017136 + N417 * 0.043261 + N4 * 0.97177
N4 = 0.0420411 + N10 * (−0.798879) + N10 * N5 * 0.0183474 + N5 * 1.73494
N5 = −0.139265 + N557 * 0.116562 + N557 * N6 * (−0.0776664) + N6 * 1.09821
N6 = −0.00169154 + N13 * 0.233573 + N7 * 0.76791
N7 = 0.00380157 + N37 * (−0.441596) + N8 * 1.43826
N8 = −0.0380351 + N485 * 0.0528034 + N10 * 0.98056
N485 = 1.55161 + “Area of Depressions (B)” * 0.418455 + “Impervious Area (NB)” * (−1.30245)
N37 = −0.517217 + N582 * 0.446059 + N582 * N48 * (−0.232074) + N48 * 1.27799
N13 = 0.0168198 + N577 * N17 * 0.118392 + N17 * 0.847431
N17 = 0.139865 + N160 * (−0.286248) + N160 * N26 * 0.0596844 + N26 * 1.07675
N26 = −0.353885 + N516 * 0.315815 + N516 * N41 * (−0.163637) + N41 * 1.19247
N41 = 0.0928836 + N72 * 0.485289 + N72 * N73 * 0.0511319 + N73 * 0.358616
N73 = −0.77541 + N550 * 0.688331 + N550 * N134 * (−0.35995) + N134 * 1.41775
N72 = −0.89717 + N521 * 0.800161 + N521 * N160 * (−0.393065) + N160 * 1.45412
N516 = 1.4074 + N570 * (−1.29801) + N570 * N571 * 2.07364 + N571 * (−1.29709)
N571 = 1.09102 + “Quality of Water (B)” * 0.599403 + “Quality of Water (B)” * “Average Slope of the Watershed (NB)” * (−0.259075) + “Average Slope of the Watershed (NB)” * (−0.370909)
N160 = 0.132042 + N531 * N372 * 0.488231 + N372 * 0.309744

N372 = 0.798356 + N448 * (−0.427063) + N448 * N449 * 0.811558 + N449 * (−0.299749)
N449 = −0.0403775 + N482 * N549 * 0.910412
N448 = 0.587093 + N478 * (−0.485373) + N478 * N556 * 1.27261 + N556 * (−0.483023)
N531 = −0.0196334 + N572 * N578 * 0.892527
N572 = 1.2324 + (Evapo-transpiration (NB)) * (−0.632739) + "Area of Depressions (B)" * 0.465516
N577 = 0.139102 + N586 * N587 * 0.76865
N587 = 1.02867 + "Area of Depressions (B)" * "Area of the Watershed (B)" * 0.767249 + "Area of the Watershed (B)" * (−0.143432)
N557 = −0.138017 + N582 * N586 * 0.985108
N586 = 1.35347 + Runoff (NB) * (−0.570914) + Runoff (NB) * "Area of the Watershed (B)" * 0.292825
N10 = 0.0274883 + N511 * N11 * 0.0584066 + N11 * 0.904545
N11 = −0.0257137 + N554 * N15 * (−0.105004) + N15 * 1.14778
N15 = 0.18417 + N134 * (−0.517164) + N134 * N33 * 0.0784919 + N33 * 1.241
N33 = −0.404285 + N555 * 0.34761 + N555 * N48 * (−0.190176) + N48 * 1.23237
N48 = 0.090972 + N63 * 0.551897 + N63 * N84 * 0.0505496 + N84 * 0.294549
N84 = −0.62683 + N487 * 0.591373 + N487 * N220 * (−0.224009) + N220 * 1.22973
N220 = 0.590601 + N431 * (−0.143019) + N431 * N407 * 0.617798 + N407 * (−0.164494)
N407 = 0.0810642 + N475 * N532 * 0.807525
N532 = −0.069413 + N570 * N578 * 0.931841
N578 = 1.11461 + Runoff (NB) * (−0.424262) + "Quality of Water (B)" * 0.447075
N475 = 1.15717 + N486 * (−0.887408) + N486 * N561 * 1.64646 + N561 * (−1.01115)
N561 = 2.00201 + (Evapo-transpiration (NB)) * (−1.12919) + (Evapo-transpiration (NB)) * "Average Slope of the Watershed (NB)" * 0.915424 + "Average Slope of the Watershed (NB)" * (−0.999369)
N486 = 1.68537 + "Impervious Area (NB)" * (−1.29783) + "Area of the Watershed (B)" * 0.140457
N431 = −0.0527887 + N482 * N550 * 0.921192
N550 = 0.545753 + Rainfall (B) * 0.832901 + "Area of Depressions (B)" * 0.382123
N482 = 2.18457 + Runoff (NB) * (−0.836206) + Runoff (NB) * "Impervious Area (NB)" * 0.815368 + "Impervious Area (NB)" * (−1.72564)
N487 = 0.0511042 + N549 * N556 * 0.83671
N556 = 1.14743 + (Evapo-transpiration (NB)) * (−0.560821) + "Area of Forest Cover (B)" * 0.586441
N549 = 0.587138 + Rainfall (B) * 0.870545 + "Area of the Watershed (B)" * 0.257037

N63 = −0.787379 + N521 * 0.702385 + N521 * N134 * (−0.377679) + N134 * 1.4392
N555 = −0.0498469 + N582 * N585 * 0.916084
N582 = 0.93698 + “Area of Depressions (B)” * 0.856787 + “Area of Depressions (B)” * “Average Slope of the Watershed (NB)” * (−0.850883)
N134 = 0.0765313 + N560 * N354 * 0.608509 + N354 * 0.230709
N354 = 0.919431 + N419 * (−0.400844) + N419 * N463 * 0.893076 + N463 * (−0.549426)
N463 = 0.793904 + N480 * (−0.75176) + N480 * N579 * 1.54109 + N579 * (−0.698849)
N579 = 1.8518 + Runoff (NB) * (−0.863668) + Runoff (NB) * “Average Slope of the Watershed (NB)” * 0.788531 + “Average Slope of the Watershed (NB)” * (−0.918363)
N419 = 0.0185745 + N480 * N521 * 0.862764
N480 = 2.03371 + (Evapo-transpiration (NB)) * (−0.55981) + “Impervious Area (NB)” * (−1.28387)
N560 = 0.0175898 + N584 * N585 * 0.863319
N585 = 0.829503 + “Quality of Water (B)” * 0.439838 + “Area of the Watershed (B)” * 0.153106
N584 = 1.02934 + Runoff (NB) * (−0.205513) + Runoff (NB) * “Area of Depressions (B)” * (−0.5144) + “Area of Depressions (B)” * 0.694402
N554 = 0.679979 + “Area of Forest Cover (B)” * 0.428569 + “Area of Forest Cover (B)” * “Quality of Water (B)” * 0.448189 + “Quality of Water (B)” * 0.275226
N511 = −0.0208551 + N568 * N574 * 0.893529
N568 = 0.737287 + “Area of Depressions (B)” * 0.214715 + “Area of Depressions (B)” * “Area of Forest Cover (B)” * 0.430054 + “Area of Forest Cover (B)” * 0.413725
N417 = 0.05029 + N478 * N521 * 0.836312
N521 = 0.461044 + Rainfall (B) * 0.821608 + “Area of Forest Cover (B)” * 0.58797
N529 = 0.0468191 + N570 * N574 * 0.839687
N574 = 1.68068 + (Evapo-transpiration (NB)) * (−0.62006) + Runoff (NB) * (−0.450143)
N570 = 0.734761 + “Area of Forest Cover (B)” * 0.633303 + “Area of the Watershed (B)” * 0.210435
N478 = 2.35412 + “Impervious Area (NB)” * (−2.02535) + “Impervious Area (NB)” * “Average Slope of the Watershed (NB)” * 1.33118 + “Average Slope of the Watershed (NB)” * (−1.11044)

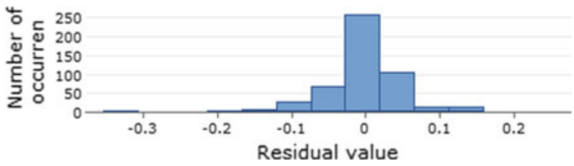


Fig. 5.7 Figure showing the histogram of residual error of the model prediction

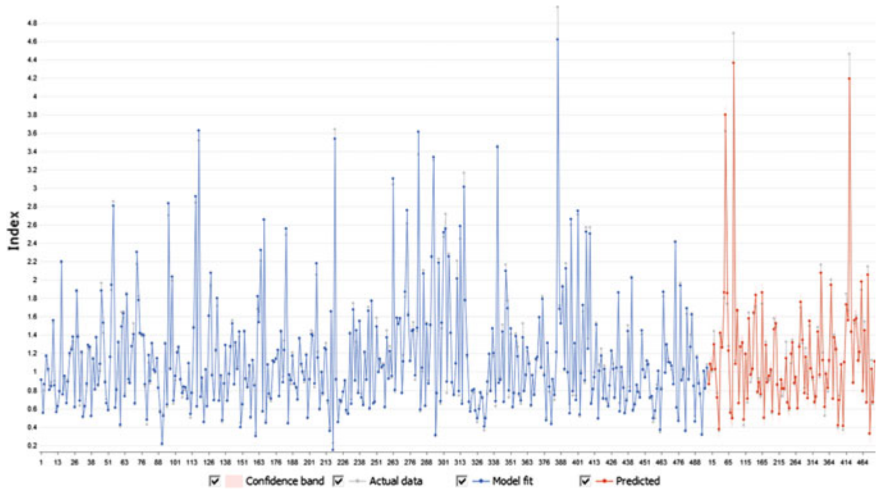


Fig. 5.8 Figure showing the variation of actual and predicted value of the index

5.1.3 Performance Metrics of ANN Model

See Figs. 5.7, 5.8 and 5.9 and Table 5.6.

Postprocessed results	Model fit	Predictions
Number of observations	398	100
Max. negative error	-0.352377	-0.325037
Max. positive error	0.252331	0.180448
Mean absolute error (MAE)	0.0330802	0.0458695
Root mean square error (RMSE)	0.0506583	0.0706669
Residual sum	-5.7121E-13	-0.664848
Standard deviation of residuals	0.0506583	0.0703535
Coefficient of determination (R^2)	0.993351	0.989509
Correlation	0.99667	0.995362

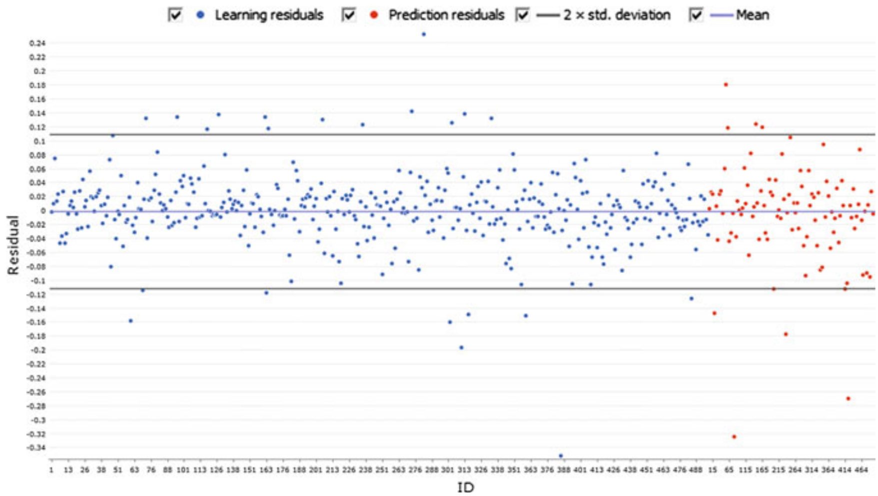


Fig. 5.9 Figure showing the deviation of model prediction from mean

Table 5.6 Table showing the rank of the river basins with respect to the input factors and vulnerability index

Rivers name	P	ET	Q	D	F	I	WQI	S	A	Index value	Rank
Nile	2	5	6	6	6	1	3	1	2	0.521	6 (MV)
Amazon	3	1	1	1	1	6	2	4	1	1.335	2
Yangtze	6	2	2	3	2	5	5	6	5	1.002	4
Mississippi	5	3	4	2	3	3	4	2	3	0.978	5
Yenisei	4	6	3	4	4	4	1	5	4	1.442	1 (LV)
Ganges	1	4	5	5	5	2	6	3	6	1.299	3

Where *MV* Most vulnerable, *LV* Least vulnerable

Plate Showing the Performance Metrics of the ANN Training.

5.1.4 Development of the Climate Model

See Figs. 5.10, 5.11 and 5.12.

Y1 = 0.000485935 + N23 * (−0.170203) + N2 * 1.16895
N2 = −0.00879239 + N581 * N3 * (−0.0726325) + N3 * 1.05795
N3 = 0.000502613 + N7 * (−0.731735) + N4 * 1.73044
N4 = 0.0107303 + N601 * 0.0102718 + N601 * N5 * 0.111296 + N5 * 0.910046

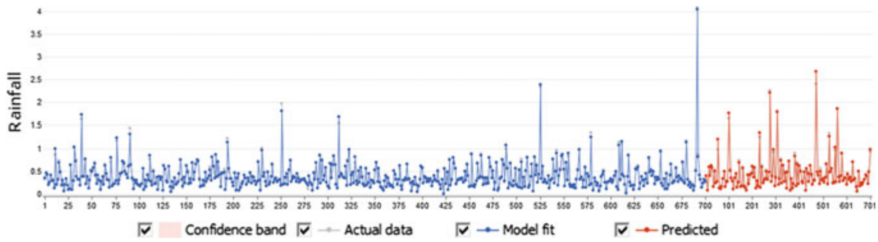


Fig. 5.10 Figure showing the comparison of actual and predicted index values for the climate model

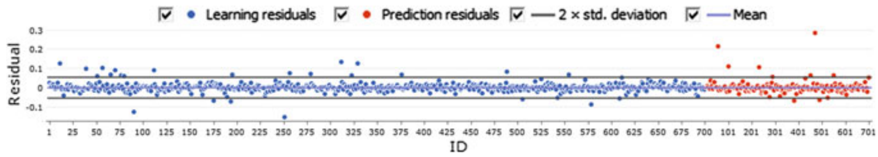


Fig. 5.11 Figure showing the residual error of the model

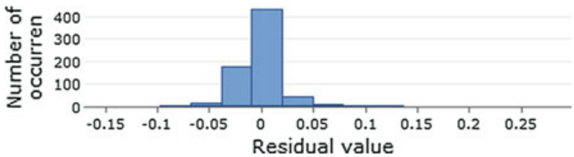


Fig. 5.12 Figure showing the histogram of residual errors

N5 = 0.00125801 + N44 * (−0.458153) + N6 * 1.45491
N6 = −0.0137961 + N594 * 0.0539575 + N7 * 0.981619
N44 = 0.0194448 + N188 * 0.298425 + N188 * N80 * 0.0442828 + N80 * 0.624668
N80 = −0.172226 + N674 * 0.444667 + N674 * N200 * (−0.691029) + N200 * 1.29339
N601 = 0.937113 + Urbanization * (−0.517703) + Urbanization * Industrialization * 0.587742 + Industrialization * (−0.868157)
N7 = 0.0140046 + N583 * N8 * 0.0920292 + N8 * 0.919623
N8 = 0.00440246 + N574 * 0.0234806 + N574 * N9 * 0.0646544 + N9 * 0.932718
N9 = 0.00401038 + N285 * (−0.141306) + N11 * 1.13096
N11 = −0.0174039 + N594 * 0.0558899 + N594 * N15 * (−0.0217114) + N15 * 0.999094
N15 = −0.00148795 + N67 * 0.322592 + N23 * 0.681245
N67 = 0.0323837 + N583 * 0.0158317 + N583 * N95 * 0.248414 + N95 * 0.782184

N95 = −0.114323 + N676 * 0.327505 + N676 * N211 * (−0.174423) + N211 * 1.04101
N211 = 0.0754485 + N276 * 0.695214 + N276 * N337 * 0.190887
N337 = 0.190276 + N482 * N526 * 1.01284
N526 = 0.193721 + N600 * (−0.499352) + N600 * N664 * 3.80122 + N664 * (−0.476209)
N482 = 0.192645 + N583 * (−0.48227) + N583 * N669 * 3.62112 + N669 * (−0.425255)
N276 = −0.0174875 + N546 * 0.0301855 + N546 * N674 * 2.61426
N546 = −0.658301 + "Industrialization, cubert" * 0.869718 + "Industrialization, cubert" * N690 * (−4.4118) + N690 * 4.31957
N594 = 0.123403 + N650 * N652 * 1.63843
N652 = −0.00376991 + N703 * N719 * 2.6071
N703 = 0.137439 + Urbanization * (−0.199923) + "GHG, cubert" * 0.472859
N650 = −0.00342745 + N714 * N719 * 2.60345
N719 = 0.479869 + "Cloud Cover" * 0.133579 + Agriculturalization * (−0.321208)
N714 = 0.0585056 + Humidity * (−1.73788) + Humidity * "Humidity, cubert" * 1.59941 + "Humidity, cubert" * 0.705003
N285 = 0.0335288 + N448 * N717 * 2.33077
N717 = −0.22599 + N723 * 0.879284 + N733 * 0.703488
N733 = 0.564915 + "Cloud Cover" * 0.121218 + "Urbanization, cubert" * (−0.313084)
N723 = −0.0475337 + "Cloud Cover" * 0.139353 + "GHG, cubert" * 0.489368
N448 = 0.253948 + N580 * (−0.611397) + N580 * N663 * 3.96096 + N663 * (−0.591181)
N663 = 0.0320743 + "Humidity, cubert" * 1.05533 + "Humidity, cubert" * "Agriculturalization, cubert" * (−0.752349)
N574 = 0.0102236 + N635 * N676 * 2.50276
N635 = 0.55119 + Industrialization * (−0.554054) + ""Cloud Cover", cubert" * 0.151392
N583 = 1.60448 + Urbanization * (−1.03987) + Urbanization * "Industrialization, cubert" * 1.07873 + "Industrialization, cubert" * (−1.46262)
N581 = 0.0344847 + "GHG, cubert" * 1.3248 + "GHG, cubert" * "Industrialization, cubert" * (−1.1368)
N23 = 0.0293531 + N361 * (−0.249341) + N361 * N49 * 0.0400652 + N49 * 1.14997
N49 = −0.12179 + N686 * 0.306245 + N686 * N77 * (−0.574328) + N77 * 1.24963
N77 = −0.00650383 + N188 * 0.50032 + N200 * 0.516452
N200 = 0.0902692 + N545 * (−0.03771) + N545 * N306 * 0.343261 + N306 * 0.62533
N306 = 0.375921 + N479 * (−1.28016) + N479 * N726 * 6.05127 + N726 * (−1.01994)
N726 = 0.193241 + N729 * N731 * 1.25626

N731 = 0.25874 + "“Cloud Cover”, cubert" * 0.462687 + "“Cloud Cover”, cubert" * “Urbanization, cubert” * (−0.381968)
N479 = 0.00648783 + N576 * N676 * 2.59444 + N676 * (−0.0259618)
N676 = 0.0855881 + GHG * 0.309484 + Humidity * 0.330638
N576 = 2.38535 + “Industrialization, cubert” * (−2.21817) + “Industrialization, cubert” * “Agriculturalization, cubert” * 1.86137 + “Agriculturalization, cubert” * (−1.84746)
N545 = 0.392457 + N618 * (−1.01184) + N618 * N690 * 5.07045 + N690 * (−0.970574)
N690 = 1.74869 + “Urbanization, cubert” * (−1.27286) + “Urbanization, cubert” * “Agriculturalization, cubert” * 1.26626 + “Agriculturalization, cubert” * (−1.48624)
N618 = 1.13954 + Industrialization * “Industrialization, cubert” * 0.15074 + “Industrialization, cubert” * (−1.08937)
N188 = −0.212814 + N674 * 0.606282 + N315 * 0.942513
N315 = 0.167092 + N469 * 0.145773 + N469 * N518 * 0.833626
N518 = 0.190814 + N600 * (−0.489207) + N600 * N669 * 3.70347 + N669 * (−0.442225)
N669 = 0.542853 + GHG * 0.459352 + GHG * “Agriculturalization, cubert” * (−0.176531) + “Agriculturalization, cubert” * (−0.421447)
N600 = 1.35425 + Industrialization * (−1.37623) + Industrialization * “Urbanization, cubert” * 1.05963 + “Urbanization, cubert” * (−0.895054)
N469 = 0.225168 + N580 * (−0.5693) + N580 * N664 * 3.93933 + N664 * (−0.545337)
N664 = 0.384547 + Humidity * 0.353833 + Agriculturalization * (−0.318562)
N674 = −0.259897 + N711 * 0.838 + N715 * 0.832209
N715 = −0.0451898 + “Cloud Cover” * 0.140059 + “Humidity, cubert” * 0.500679
N711 = 0.152621 + GHG * 0.338048 + “Cloud Cover” * 0.138405
N686 = 0.0136094 + N721 * N729 * 2.4873
N729 = 0.431359 + “Cloud Cover” * 0.123533 + Urbanization * (−0.204995)
N721 = 0.253234 + GHG * “GHG, cubert” * 0.32184
N361 = 0.156869 + N471 * N640 * 1.78293 + N640 * (−0.154074)
N640 = −0.00419721 + N695 * N718 * 2.6091
N718 = 0.642887 + "“Cloud Cover”, cubert" * 0.176438 + “Agriculturalization, cubert” * (−0.515896)
N695 = 0.329313 + GHG * 0.327676 + Urbanization * (−0.198828)
N471 = 0.240448 + N580 * (−0.5994) + N580 * N668 * 3.99045 + N668 * (−0.577513)
N668 = 0.0330248 + Agriculturalization * “Humidity, cubert” * (−0.450508) + “Humidity, cubert” * 0.712973
N580 = 2.51029 + “Urbanization, cubert” * (−1.88228) + “Urbanization, cubert” * “Industrialization, cubert” * 1.99403 + “Industrialization, cubert” * (−2.43533)

Error measure	Absolute	Target: Rainfall of vulnerability_models
Postprocessed results	Model fit	Predictions
Number of observations	561	140
Max. negative error	-0.155556	-0.0702967
Max. positive error	0.133149	0.283486
Mean absolute error (MAE)	0.0145864	0.0189946
Root mean square error (RMSE)	0.0238865	0.0383782
Residual sum	-3.82971E-13	0.28557
Standard deviation of residuals	0.0238865	0.038324
Coefficient of determination (R^2)	0.993579	0.989645
Correlation	0.996785	0.995973

Plate Showing the Performance Measure of the Climate Model with respect to Rainfall Probability.

See Figs. 5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19, 5.20, 5.21, 5.22, 5.23, 5.24, 5.25, 5.26, 5.27, 5.28, 5.29, 5.30, 5.31, 5.32 and 5.33.

$$Y1 = 0.121557 + N603 * (-0.0424524) + N2 * 1.01049$$
$$N2 = 0.00459248 + N11 * (-0.600924) + N3 * 1.59972$$
$$N3 = -0.015551 + N579 * 0.0290796 + N579 * N4 * 0.00367063 + N4 * 0.95773$$

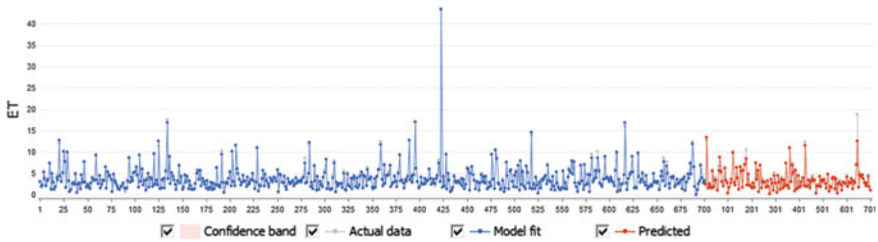


Fig. 5.13 Figure showing the variation of actual and predicted value of ET probability

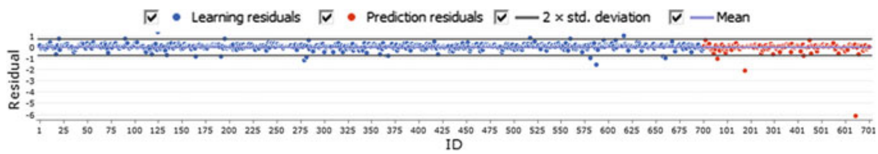


Fig. 5.14 Figure showing the residual error of the model predicting ET probability

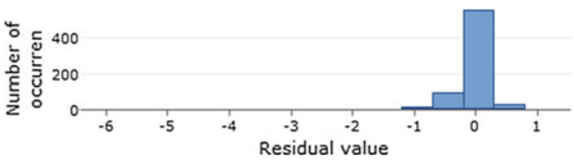


Fig. 5.15 Figure showing the histogram of residual errors for the model predicting ET probability

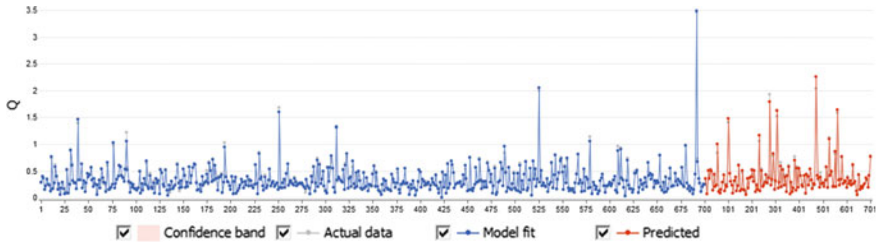


Fig. 5.16 Figure showing the variations of actual and predicted value of Q probability

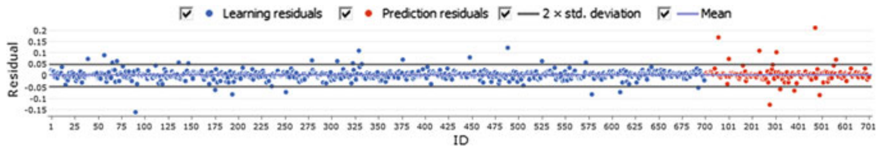


Fig. 5.17 Figure showing the deviations of residual errors for the model predicting Q probability

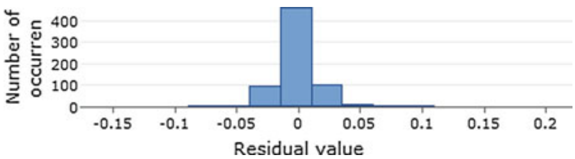


Fig. 5.18 Figure showing the histogram of residual error for model predicting Q probability

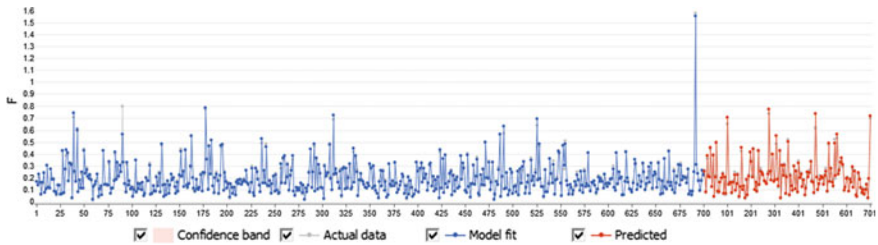


Fig. 5.19 Figure showing the variations of actual and predicted F probability value from the ANN model

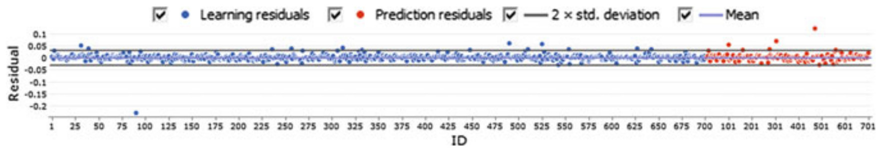


Fig. 5.20 Figure showing the deviations in residual error of the model predicting the F probability

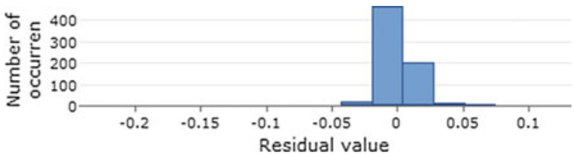


Fig. 5.21 Figure showing the histogram of residual errors of the model predicting the F probability

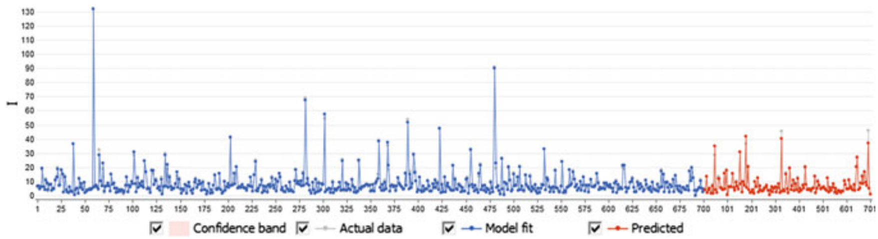


Fig. 5.22 Figure showing the variation in actual and predicted value of the I probability

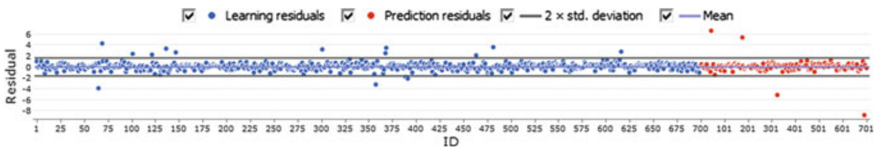


Fig. 5.23 Figure showing the deviations in residual error of the model prediciting I probability

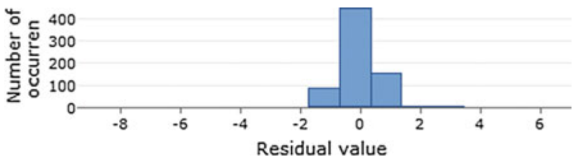


Fig. 5.24 Figure showing the histogram of residual error of the model predicting I probability

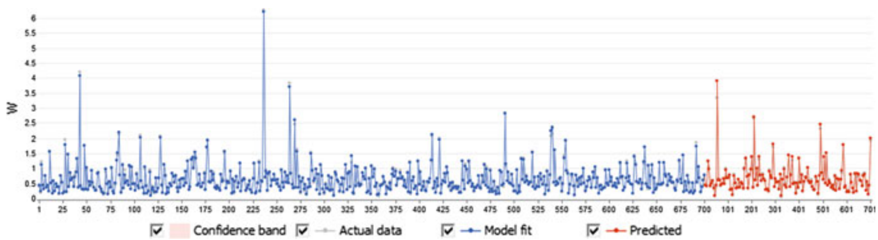


Fig. 5.25 Figure showing the variations in actual and predicted values of area of water body probability

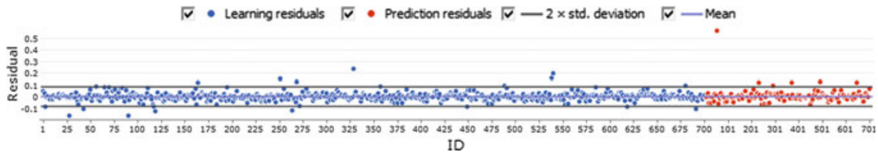


Fig. 5.26 Figure showing the deviations in residual error of the model predicting area of water body probability

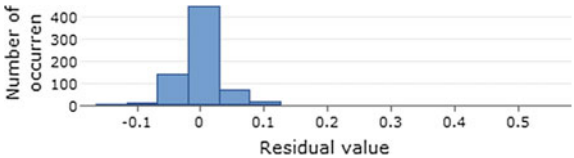


Fig. 5.27 Figure showing the histogram of residual error of the model predicting area of water body probability

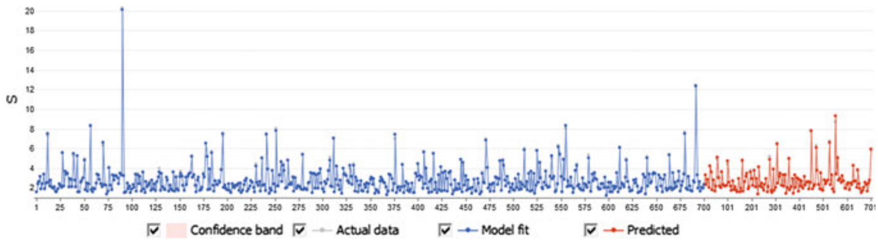


Fig. 5.28 Figure showing the variation in actual and predicted value of the slope probability

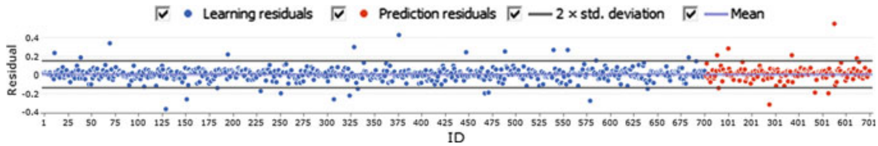


Fig. 5.29 Figure showing the deviation of residual error of the model predicting slope probability

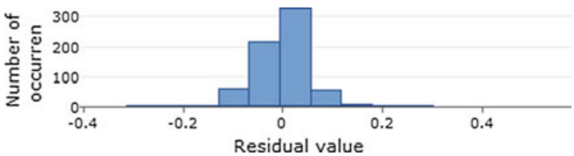


Fig. 5.30 Figure showing the histogram of residual errors of the model predicting slope probability

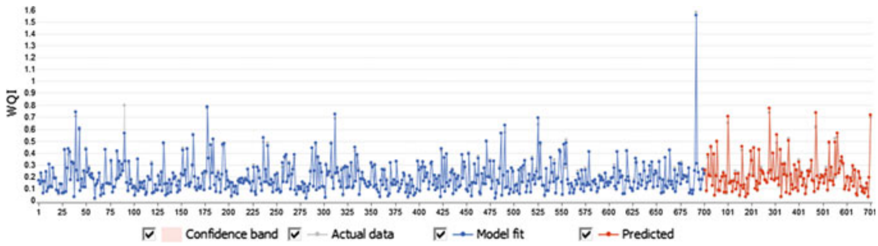


Fig. 5.31 Figure showing the variations in actual and predicted value of WQI probability

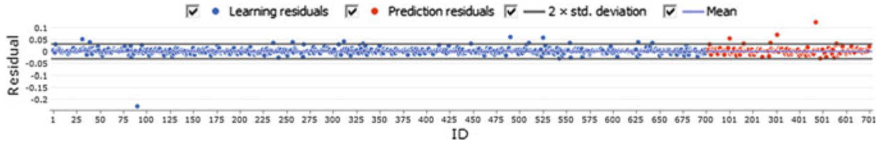


Fig. 5.32 Figure showing the deviations in residual error of the model predicting WQI probability

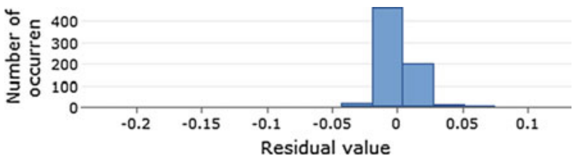


Fig. 5.33 Figure showing the histogram of residual errors of the model predicting WQI probability

N4 = −0.0600544 + N615 * 0.044135 + N615 * N7 * 0.00822027 + N7 * 0.936087
N7 = 0.046269 + N395 * (−0.131598) + N11 * 1.11943
N395 = 1.95712 + N489 * N490 * 0.0931774
N490 = 2.80487 + N580 * (−0.500966) + N580 * N598 * 0.362772 + N598 * (−0.648722)
N489 = 2.72641 + N586 * (−0.681694) + N586 * N608 * 0.42794 + N608 * (−0.678657)
N608 = 8.30722 + GHG * (−6.77359) + GHG * “Cloud Cover” * 4.67143 + “Cloud Cover” * (−4.62303)
N586 = −2.62745 + Humidity * 3.54559 + Humidity * “Industrialization, cubert” * (−10.0511) + “Industrialization, cubert” * 10.9639
N615 = 10.6792 + GHG * (−9.05336) + GHG * ““Cloud Cover”, cubert” * 6.21069 + ““Cloud Cover”, cubert” * (−6.29739)
N579 = 1.51034 + Industrialization * 12.9669 + Industrialization * “Humidity, cubert” * (−11.6548)
N11 = −0.0118831 + N18 * 0.564582 + N30 * 0.438542
N30 = 0.0990555 + N430 * (−0.248043) + N60 * 1.222

N60 = −1.50721 + N602 * 0.362365 + N602 * N83 * (−0.0687854) + N83 * 1.32786
N83 = −0.0485949 + N179 * 0.430588 + N193 * 0.582189
N179 = −1.46569 + N688 * 0.425631 + N688 * N374 * 0.0946917 + N374 * 0.595839
N374 = 1.45809 + N442 * N457 * 0.0496965 + N457 * 0.337439
N457 = 3.50005 + N580 * (−0.834409) + N580 * N604 * 0.459642 + N604 * (−0.861032)
N604 = 8.02688 + “Cloud Cover” * (−4.3891) + “Cloud Cover” * Humidity * 4.77742 + Humidity * (−6.82726)
N580 = −1.15677 + “GHG, cubert” * “Industrialization, cubert” * (−10.1453) + “Industrialization, cubert” * 14.2013
N442 = 3.57278 + N584 * (−0.933802) + N584 * N597 * 0.492661 + N597 * (−0.89334)
N597 = 18.4665 + “GHG, cubert” * (−16.311) + “GHG, cubert” * ““Cloud Cover”, cubert” * 12.1605 + ““Cloud Cover”, cubert” * (−12.3872)
N584 = −4.99103 + “Humidity, cubert” * 5.53161 + “Humidity, cubert” * “Industrialization, cubert” * (−15.4549) + “Industrialization, cubert” * 17.5349
N688 = 1.77788 + Urbanization * 1.8921 + Agriculturalization * 2.12523
N430 = 2.58056 + N499 * N547 * 0.158461 + N547 * (−0.429245)
N547 = 2.79678 + N616 * (−0.670443) + N616 * N620 * 0.423405 + N620 * (−0.690768)
N620 = 1.50854 + GHG * “Agriculturalization, cubert” * (−5.66039) + “Agriculturalization, cubert” * 5.83277
N616 = 3.76027 + Humidity * (−2.08333) + Humidity * Urbanization * (−4.45587) + Urbanization * 3.98249
N499 = 3.0885 + N585 * (−0.732776) + N585 * N614 * 0.434714 + N614 * (−0.756697)
N585 = −2.80707 + GHG * 3.38738 + GHG * “Industrialization, cubert” * (−10.369) + “Industrialization, cubert” * 11.6868
N18 = 0.0870067 + N367 * (−0.39713) + N37 * 1.37425
N37 = −0.0361793 + N73 * 0.466853 + N79 * 0.54266
N79 = −2.008 + N602 * 0.51431 + N602 * N247 * (−0.066995) + N247 * 1.2952
N247 = 0.355287 + N676 * N310 * 0.126672 + N310 * 0.408316
N310 = 1.4272 + N474 * 0.249944 + N474 * N508 * 0.0765702
N508 = 4.41199 + N593 * (−1.16383) + N593 * N599 * 0.557724 + N599 * (−1.1286)
N599 = 4.22157 + “Humidity, cubert” * (−3.96438) + “Humidity, cubert” * “Agriculturalization, cubert” * (−3.93929) + “Agriculturalization, cubert” * 6.13547
N593 = 13.9794 + “Cloud Cover” * (−9.44385) + “Cloud Cover” * “GHG, cubert” * 9.46184 + “GHG, cubert” * (−12.0032)
N474 = 0.373127 + N582 * N606 * 0.265955 + N606 * (−0.119213)
N606 = 1.88023 + “GHG, cubert” * “Urbanization, cubert” * (−9.38735) + “Urbanization, cubert” * 9.52729

N582 = 1.48515 + Humidity * Industrialization * (−7.7302) + Industrialization * 8.1094
N676 = −6.42294 + N683 * 2.09217 + N683 * N692 * (−0.329385) + N692 * 1.8802
N692 = 5.03844 + Urbanization * 1.72856 + "“Cloud Cover”, cubert" * (−2.85353)
N683 = 1.4191 + "“Cloud Cover”, cubert" * "Agriculturalization, cubert" * (−3.81731) + "Agriculturalization, cubert" * 6.02344
N602 = 0.854807 + Industrialization * 4.01723 + Industrialization * Agriculturalization * 1.23566 + Agriculturalization * 1.28943
N73 = −1.94348 + N625 * 0.410054 + N625 * N193 * (−0.114244) + N193 * 1.5865
N193 = 1.04128 + N381 * N436 * 0.0341284 + N436 * 0.537316
N436 = 0.202983 + N559 * N588 * 0.253893 + N588 * (−0.0304211)
N588 = 0.040333 + N626 * N686 * 0.259794
N686 = 1.82128 + "Cloud Cover" * "Urbanization, cubert" * (−2.74352) + "Urbanization, cubert" * 3.97597
N626 = 1.47503 + Industrialization * 4.67153
N559 = 3.15172 + N624 * (−0.79852) + N624 * N627 * 0.46416 + N627 * (−0.804859)
N627 = 7.06236 + Humidity * (−20.0616) + Humidity * "Humidity, cubert" * 15.4081
N624 = 4.31592 + GHG * (−3.01838) + GHG * Agriculturalization * (−2.58306) + Agriculturalization * 3.21417
N381 = 1.34781 + N452 * 0.466355 + N452 * N532 * 0.0536309 + N532 * (−0.0923389)
N532 = 5.30583 + N601 * (−1.42097) + N601 * N614 * 0.598221 + N614 * (−1.27056)
N614 = 10.3242 + Humidity * (−9.05359) + Humidity * "“Cloud Cover”, cubert" * 6.20554 + "“Cloud Cover”, cubert" * (−6.03633)
N601 = 2.88178 + Urbanization * 11.1734 + Urbanization * "GHG, cubert" * (−12.607)
N452 = 2.77803 + N573 * (−0.759904) + N573 * N603 * 0.447759 + N603 * (−0.682956)
N573 = 16.4366 + Humidity * (−17.1877) + Humidity * "GHG, cubert" * 17.389 + "GHG, cubert" * (−14.4398)
N625 = 4.43008 + Humidity * (−3.59152) + Humidity * Agriculturalization * (−1.49679) + Agriculturalization * 2.71402
N367 = 1.27006 + N680 * (−0.313484) + N680 * N460 * 0.324941 + N460 * (−0.26129)
N460 = 2.36831 + N572 * (−0.38658) + N572 * N598 * 0.324805 + N598 * (−0.502677)
N598 = 1.69395 + "Humidity, cubert" * "Urbanization, cubert" * (−9.11582) + "Urbanization, cubert" * 9.40201

N572 = 1.44325 + Industrialization * 15.6106 + Industrialization * “GHG, cubert” * (−14.5346)
N680 = 1.38111 + “Cloud Cover” * “Agriculturalization, cubert” * (−2.8327) + “Agriculturalization, cubert” * 4.65363
N603 = −0.994452 + “Cloud Cover” * “Industrialization, cubert” * (−2.95544) + “Industrialization, cubert” * 7.88254
Y1 = 0.00994771 + N567 * (−0.0109321) + N567 * N2 * 0.0734732 + N2 * 0.949038
N2 = 0.000423613 + N12 * (−0.358773) + N3 * 1.35749
N3 = −0.000242552 + N424 * (−0.0612018) + N424 * N4 * (−0.0143805) + N4 * 1.06895
N4 = −0.0151099 + N646 * 0.059562 + N5 * 0.986279
N5 = −0.0044403 + N30 * (−0.841235) + N30 * N6 * (−0.0136065) + N6 * 1.8618
N6 = −0.0117906 + N586 * 0.0511907 + N586 * N8 * (−0.0158247) + N8 * 0.990961
N8 = 0.00917968 + N479 * 0.037193 + N479 * N12 * 0.0606775 + N12 * 0.906768
N479 = 0.163749 + N580 * (−0.48227) + N580 * N666 * 4.26014 + N666 * (−0.425255)
N580 = 1.36381 + Urbanization * (−0.88389) + Urbanization * “Industrialization, cubert” * 0.916918 + “Industrialization, cubert” * (−1.24323)
N586 = 0.357132 + Humidity * 0.43831 + Humidity * Industrialization * (−0.311105) + Industrialization * (−0.316023)
N30 = −0.0858979 + N683 * 0.250305 + N683 * N46 * (−0.618722) + N46 * 1.23235
N46 = 0.00838261 + N358 * (−0.291447) + N70 * 1.26602
N646 = −0.00357859 + N711 * N717 * 3.0696
N717 = 0.349908 + Agriculturalization * (−0.271004) + ““Cloud Cover”, cubert” * 0.15292
N711 = 0.0497298 + Humidity * (−1.4772) + Humidity * “Humidity, cubert” * 1.3595 + “Humidity, cubert” * 0.599252
N424 = 0.12 + N557 * N599 * 2.3266 + N599 * (−0.212795)
N599 = 0.00879273 + N677 * N686 * 2.94577
N686 = 0.0166122 + “Humidity, cubert” * 0.746518 + “Humidity, cubert” * “Urbanization, cubert” * (−0.412857)
N557 = 0.120455 + N609 * (−0.32747) + N609 * N675 * 3.86754 + N675 * (−0.317997)
N675 = 0.35404 + “GHG, cubert” * 0.400137 + “Agriculturalization, cubert” * (−0.431569)
N609 = 0.835634 + “Cloud Cover” * 0.103583 + “Industrialization, cubert” * (−0.744782)
N12 = 0.00370183 + N169 * (−0.747346) + N26 * 1.73612
N26 = 0.0137676 + N51 * 0.523291 + N51 * N57 * 0.0373503 + N57 * 0.415558

N57 = −0.0557782 + N607 * 0.161779 + N607 * N102 * (−0.20549) + N102 * 1.08766
N102 = 0.0112421 + N358 * (−0.463313) + N174 * 1.42921
N174 = 0.0542096 + N271 * 0.531645 + N271 * N295 * 0.219742 + N295 * 0.194557
N295 = 0.0335915 + N449 * N702 * 2.79628 + N702 * (−0.03413)
N702 = −0.200978 + N721 * 0.885134 + N726 * 0.724597
N721 = −0.106954 + "GHG, cubert" * 0.416682 + ""Cloud Cover", cubert" * 0.168357
N271 = −0.0116673 + N543 * 0.046027 + N543 * N664 * 2.99431
N664 = −0.321326 + N712 * 1.02616 + N712 * N718 * (−0.213753) + N718 * 1.01938
N358 = 0.133339 + N468 * N637 * 2.09756 + N637 * (−0.154074)
N637 = −0.00356763 + N692 * N715 * 3.06953
N715 = 0.546454 + ""Cloud Cover", cubert" * 0.149972 + "Agriculturalization, cubert" * (−0.438512)
N692 = 0.279916 + GHG * 0.278525 + Urbanization * (−0.169004)
N468 = 0.204381 + N577 * (−0.5994) + N577 * N665 * 4.69464 + N665 * (−0.577513)
N665 = 0.0280711 + Agriculturalization * "Humidity, cubert" * (−0.382932) + "Humidity, cubert" * 0.606027
N607 = 0.155731 + N623 * N649 * 1.80663 + N649 * (−0.141765)
N649 = −0.00320442 + N700 * N716 * 3.06718
N700 = 0.116823 + Urbanization * (−0.169935) + "GHG, cubert" * 0.401931
N623 = 0.000231754 + N678 * N716 * 2.97157 + N716 * 0.0203047
N716 = 0.407888 + "Cloud Cover" * 0.113542 + Agriculturalization * (−0.273027)
N678 = −0.0831561 + Humidity * 0.283592 + "GHG, cubert" * 0.379959
N51 = −0.103371 + N683 * 0.306378 + N683 * N70 * (−0.668512) + N70 * 1.24643
N70 = −0.00550411 + N195 * 0.493169 + N196 * 0.52353
N196 = 0.0767288 + N542 * (−0.03771) + N542 * N303 * 0.403837 + N303 * 0.62533
N303 = 0.319532 + N476 * (−1.28016) + N476 * N723 * 7.11914 + N723 * (−1.01994)
N723 = 0.164255 + N726 * N728 * 1.47795
N728 = 0.219929 + ""Cloud Cover", cubert" * 0.393284 + ""Cloud Cover", cubert" * "Urbanization, cubert" * (−0.324673)
N476 = 0.00551465 + N573 * N673 * 3.05228 + N673 * (−0.0259618)
N673 = 0.0727499 + GHG * 0.263062 + Humidity * 0.281042
N573 = 2.02755 + "Industrialization, cubert" * (−1.88544) + "Industrialization, cubert" * "Agriculturalization, cubert" * 1.58216 + "Agriculturalization, cubert" * (−1.57034)
N542 = 0.333588 + N615 * (−1.01184) + N615 * N687 * 5.96524 + N687 * (−0.970574)

N615 = 0.968607 + Industrialization * “Industrialization, cubert” * 0.128129 + “Industrialization, cubert” * (−0.925963)
N195 = −0.178879 + N670 * 0.600867 + N312 * 0.941819
N312 = 0.142028 + N466 * 0.145773 + N466 * N515 * 0.980737
N515 = 0.162192 + N597 * (−0.489207) + N597 * N666 * 4.35703 + N666 * (−0.442225)
N666 = 0.461425 + GHG * 0.390449 + GHG * “Agriculturalization, cubert” * (−0.150051) + “Agriculturalization, cubert” * (−0.35823)
N597 = 1.15112 + Industrialization * (−1.16979) + Industrialization * “Urbanization, cubert” * 0.900689 + “Urbanization, cubert” * (−0.760796)
N466 = 0.191393 + N577 * (−0.5693) + N577 * N661 * 4.63451 + N661 * (−0.545337)
N661 = 0.326865 + Humidity * 0.300758 + Agriculturalization * (−0.270778)
N670 = −0.226681 + N709 * 0.845832 + N712 * 0.841877
N712 = −0.0384113 + “Cloud Cover” * 0.11905 + “Humidity, cubert” * 0.425577
N709 = 0.0633124 + GHG * 0.288029 + ““Cloud Cover”, cubert” * 0.167901
N683 = 0.011568 + N718 * N726 * 2.92624
N726 = 0.366655 + “Cloud Cover” * 0.105003 + Urbanization * (−0.174246)
N169 = 0.0500652 + N274 * 0.529395 + N274 * N283 * 0.20229 + N283 * 0.218088
N283 = 0.0249643 + N449 * N714 * 2.77592
N714 = −0.192092 + N720 * 0.879284 + N730 * 0.703488
N730 = 0.480178 + “Cloud Cover” * 0.103035 + “Urbanization, cubert” * (−0.266121)
N720 = −0.0404037 + “Cloud Cover” * 0.11845 + “GHG, cubert” * 0.415963
N449 = 0.200156 + N577 * (−0.582477) + N577 * N658 * 4.61557 + N658 * (−0.554198)
N658 = 0.523279 + Humidity * 0.302624 + “Agriculturalization, cubert” * (−0.442248)
N577 = 2.13374 + “Urbanization, cubert” * (−1.59994) + “Urbanization, cubert” * “Industrialization, cubert” * 1.69492 + “Industrialization, cubert” * (−2.07003)
N274 = −0.0101701 + N543 * 0.0424349 + N543 * N663 * 2.98886
N663 = −0.356633 + N705 * 1.13085 + N705 * N718 * (−0.525385) + N718 * 1.12482
N718 = 0.215249 + GHG * “GHG, cubert” * 0.273564
N705 = −0.106056 + ““Cloud Cover”, cubert” * 0.169944 + “Humidity, cubert” * 0.426612
N543 = −0.559556 + “Industrialization, cubert” * 0.73926 + “Industrialization, cubert” * N687 * (−4.4118) + N687 * 4.31957
N687 = 1.48638 + “Urbanization, cubert” * (−1.08193) + “Urbanization, cubert” * “Agriculturalization, cubert” * 1.07632 + “Agriculturalization, cubert” * (−1.2633)
N567 = 0.00377468 + N630 * N677 * 3.0562 + N677 * (−0.019625)
N677 = 0.161447 + Agriculturalization * (−0.266275) + “GHG, cubert” * 0.401611
N630 = 0.518101 + “Cloud Cover” * 0.091985 + Industrialization * (−0.47066)

Y1 = 0.0013813 + N351 * (−0.0778767) + N9 * 1.0707
N9 = 0.000531352 + N92 * (−0.506843) + N15 * 1.50408
N15 = −0.000435491 + N37 * 0.528961 + N42 * 0.473303
N42 = 0.0031165 + N404 * (−0.163367) + N61 * 1.14716
N61 = −0.00186673 + N105 * 0.614611 + N149 * 0.395094
N149 = 0.0202959 + N268 * 0.372651 + N268 * N272 * 0.39191 + N272 * 0.414902
N272 = 0.000117684 + N591 * N589 * 5.16712
N589 = 0.138906 + N623 * (−0.743052) + N623 * N687 * 8.86597 + N687 * (−0.685942)
N623 = 0.383793 + GHG * (−0.146582) + GHG * Industrialization * 0.193695 + Industrialization * (−0.334879)
N268 = 0.00326879 + N485 * 0.0623921 + N485 * N681 * 4.77561
N681 = 0.0657757 + N700 * N710 * 4.6462 + N710 * (−0.241886)
N710 = 0.400164 + GHG * (−0.251062) + GHG * "Urbanization, cubert" * 0.259619 + "Urbanization, cubert" * (−0.238085)
N700 = 0.153737 + GHG * (−0.0483166) + "Cloud Cover" * 0.124412
N485 = 0.0017953 + N594 * N613 * 5.11577
N613 = 0.82824 + "Urbanization, cubert" * (−0.467403) + "Urbanization, cubert" * "Industrialization, cubert" * 0.457201 + "Industrialization, cubert" * (−0.721276)
N594 = 0.2213 + Humidity * 0.267458 + "Agriculturalization, cubert" * (−0.201021)
N105 = −0.0553934 + "GHG, cubert" * 0.072871 + "GHG, cubert" * N260 * (−0.875541) + N260 * 1.66072
N404 = 0.0485426 + N490 * 0.246961 + N490 * N588 * 2.23882
N588 = 0.00770761 + N624 * N674 * 4.95861
N674 = 0.278649 + "Cloud Cover" * 0.126821 + "Agriculturalization, cubert" * (−0.2)
N490 = 0.133842 + N580 * (−0.759913) + N580 * N691 * 9.1897 + N691 * (−0.700776)
N37 = −0.00103489 + N98 * 0.601049 + N104 * 0.404332
N104 = −0.00405066 + N260 * 0.330802 + N143 * 0.690256
N143 = 0.0338761 + N587 * (−0.0854863) + N587 * N252 * 0.766119 + N252 * 0.731393
N587 = 0.131477 + N624 * (−0.706653) + N624 * N687 * 8.69188 + N687 * (−0.650264)
N687 = 0.481008 + Urbanization * (−0.262518) + Urbanization * "Agriculturalization, cubert" * 0.254861 + "Agriculturalization, cubert" * (−0.335394)
N624 = 0.488805 + Industrialization * (−0.477014) + Industrialization * "GHG, cubert" * 0.318553 + "GHG, cubert" * (−0.237663)
N260 = 0.00421025 + N592 * N586 * 5.05923
N98 = −0.0126773 + N518 * (−0.21031) + N518 * N128 * (−0.384801) + N128 * 1.37771

N128 = 0.0100465 + N262 * 0.577902 + N262 * N496 * 0.476673 + N496 * 0.248114
N496 = 0.0266674 + N577 * N632 * 4.82113 + N632 * (−0.0774384)
N632 = −0.0014053 + N673 * N709 * 5.23718
N673 = 0.190965 + "Cloud Cover" * 0.12819 + Agriculturalization * (−0.126921)
N577 = −0.0492284 + N615 * 0.344872 + N615 * N619 * 2.58665 + N619 * 0.404258
N619 = 0.00178466 + "GHG, cubert" * (−0.112994) + "Humidity, cubert" * 0.379438
N615 = 0.624428 + GHG * (−0.319176) + GHG * "Industrialization, cubert" * 0.357416 + "Industrialization, cubert" * (−0.542914)
N518 = 0.00694672 + N599 * 0.0336049 + N599 * N601 * 4.7947
N601 = 0.187816 + ""Cloud Cover", cubert" * 0.377915 + ""Cloud Cover", cubert" * "Industrialization, cubert" * (−0.266639) + "Industrialization, cubert" * (−0.171082)
N599 = −0.0771588 + "Humidity, cubert" * 0.586649 + "Humidity, cubert" * "Agriculturalization, cubert" * (−0.286211)
N92 = −0.00197641 + N127 * 0.600306 + N158 * 0.409969
N158 = 0.0471536 + N691 * (−0.19023) + N691 * N252 * 1.71552 + N252 * 0.60071
N252 = 0.19693 + N469 * (−1.12559) + N469 * N706 * 11.2348 + N706 * (−1.05154)
N706 = −1.51496e−14 + N709 * 1
N709 = 0.295452 + GHG * (−0.133605) + GHG * Urbanization * 0.155814 + Urbanization * (−0.148758)
N469 = 0.00169998 + N592 * N595 * 5.1215
N595 = 0.930696 + "Industrialization, cubert" * (−0.813687) + "Industrialization, cubert" * "Agriculturalization, cubert" * 0.627764 + "Agriculturalization, cubert" * (−0.643786)
N592 = 0.00399528 + "Cloud Cover" * 0.131232 + Humidity * 0.269625
N691 = 0.426597 + Agriculturalization * (−0.308349) + Agriculturalization * "Urbanization, cubert" * 0.241091 + "Urbanization, cubert" * (−0.226206)
N127 = 0.165847 + N713 * (−0.866488) + N713 * N262 * 9.99158 + N262 * (−0.916245)
N262 = 0.00537939 + N591 * N586 * 5.02471
N586 = 0.194155 + N622 * (−0.998655) + N622 * N689 * 10.2155 + N689 * (−0.978963)
N622 = 0.374135 + Industrialization * (−1.00778) + Industrialization * "Industrialization, cubert" * 0.751614
N591 = −0.0731644 + Humidity * 0.27077 + ""Cloud Cover", cubert" * 0.191228
N713 = 0.2584 + "GHG, cubert" * (−0.0884291)
N351 = 0.00463127 + N484 * 0.165175 + N484 * N680 * 4.18328
N680 = 0.0417504 + N702 * N708 * 4.03635
N708 = 0.404222 + Urbanization * (−0.277415) + Urbanization * "GHG, cubert" * 0.27457 + "GHG, cubert" * (−0.233332)

N702 = 0.120078 + “GHG, cubert” * (−0.0800043) + ““Cloud Cover”, cubert” * 0.177336
N484 = 0.000111764 + N580 * (−0.139388) + N580 * N689 * 5.92649
N689 = 0.689276 + “Urbanization, cubert” * (−0.455527) + “Urbanization, cubert” * “Agriculturalization, cubert” * 0.469057 + “Agriculturalization, cubert” * (−0.557149)
N580 = 0.128332 + Humidity * 0.384407 + Humidity * Industrialization * (−0.250992) + Industrialization * (−0.110056)

Y1 = 0.332057 + N492 * N2 * 0.00279527 + N2 * 0.92319
N2 = −0.293103 + Urbanization * 0.577877 + N4 * 0.999507
N4 = −0.213681 + N505 * 0.0398226 + N8 * 0.985482
N8 = 0.360581 + N192 * (−0.478824) + N192 * N14 * 0.000625536 + N14 * 1.42432
N14 = −1.27744 + N625 * 0.167138 + N28 * 0.984142
N28 = 0.0648086 + N579 * 0.0541456 + N579 * N38 * 0.0104544 + N38 * 0.827328
N38 = −0.034916 + N354 * (−0.366167) + N354 * N65 * (−0.000304792) + N65 * 1.37595
N65 = 0.364284 + N130 * 0.508506 + N130 * N246 * 0.000907151 + N246 * 0.431396
N246 = 0.115813 + N569 * 0.139571 + N569 * N285 * 0.0232892 + N285 * 0.605673
N285 = 2.9792 + N403 * (−0.212215) + N403 * N612 * 0.118611 + N612 * (−0.177116)
N612 = −7.7465 + N633 * 0.988691 + N681 * 0.928684
N681 = 5.69079 + GHG * 1.54194 + Agriculturalization * 4.03446
N633 = −5.13334 + “Urbanization, cubert” * 2.71962 + “Industrialization, cubert” * 15.3675
N403 = 5.6631 + N470 * N471 * 0.0485197 + N471 * (−0.383125)
N569 = 13.6035 + Humidity * (−15.7016) + Agriculturalization * 4.00337
N130 = −3.5009 + N321 * 0.964625 + N584 * 0.449967
N584 = 4.29312 + N600 * 0.611717 + N600 * N605 * 0.0985407 + N605 * (−1.07149)
N605 = 0.0350673 + N635 * 0.0925757 + N635 * N675 * 0.10675
N675 = 2.5908 + Urbanization * 1.67811 + “Agriculturalization, cubert” * 6.66149
N600 = −7.57623 + N632 * 0.984624 + N676 * 0.912587
N676 = 2.51133 + GHG * 2.02118 + GHG * “Agriculturalization, cubert” * (−0.646751) + “Agriculturalization, cubert” * 6.91273
N632 = −3.97618 + Urbanization * 1.80839 + “Industrialization, cubert” * 15.339
N354 = 4.10264 + N398 * N477 * 0.0396312
N477 = 6.54862 + N568 * (−0.875507) + N568 * N631 * 0.227281 + N631 * (−0.806461)
N631 = 19.8038 + “GHG, cubert” * ““Cloud Cover”, cubert” * 1.43116 + ““Cloud Cover”, cubert” * (−16.3235)

N398 = 5.15138 + N471 * (−0.13327) + N471 * N504 * 0.0680308 + N504 * (−0.27936)
N504 = −23.8851 + “Humidity, cubert” * 29.2479 + “Humidity, cubert” * “Industrialization, cubert” * (−71.2961) + “Industrialization, cubert” * 66.2836
N471 = 59.8322 + “Cloud Cover” * (−60.2622) + “Cloud Cover” * “Humidity, cubert” * 68.1179 + “Humidity, cubert” * (−63.1692)
N579 = 13.1347 + Humidity * (−15.8187) + “Urbanization, cubert” * 3.29562
N625 = 13.0883 + GHG * 1.09989 + “Cloud Cover” * (−10.349)
N192 = −2.9178 + N603 * 0.393567 + N603 * N321 * 0.00702235 + N321 * 0.887648
N321 = 2.57532 + N379 * 0.305395 + N379 * N460 * 0.0151767 + N460 * 0.159633
N460 = 7.57764 + N511 * (−1.04167) + N511 * N599 * 0.254574 + N599 * (−0.983516)
N599 = 7.21135 + ““Cloud Cover”, cubert” * (−4.96437) + ““Cloud Cover”, cubert” * “Agriculturalization, cubert” * (−13.5948) + “Agriculturalization, cubert” * 16.6972
N511 = 26.5095 + GHG * 2.6738 + “Humidity, cubert” * (−26.7395)
N379 = 4.49307 + N470 * N497 * 0.0608076 + N497 * (−0.254241)
N497 = 2.99816 + Industrialization * 46.1966 + Industrialization * “Humidity, cubert” * (−49.1322)
N470 = 104.521 + ““Cloud Cover”, cubert” * (−100.113) + ““Cloud Cover”, cubert” * “Humidity, cubert” * 113.394 + “Humidity, cubert” * (−113.869)
N603 = 0.54065 + N635 * N682 * 0.117759 + N682 * (−0.0600796)
N682 = −1.49993 + “Urbanization, cubert” * 6.56863 + “Urbanization, cubert” * “Agriculturalization, cubert” * (−5.82898) + “Agriculturalization, cubert” * 11.0342
N635 = −2.98501 + “Industrialization, cubert” * 15.2577
N505 = 2.88775 + Humidity * Industrialization * (−29.3648) + Industrialization * 24.2861
N492 = 5.88618 + N568 * (−0.710491) + N568 * N622 * 0.207604 + N622 * (−0.731205)
N622 = 13.6456 + “Cloud Cover” * (−11.728) + “Cloud Cover” * Urbanization * 2.63167
N568 = 5.7055 + Humidity * (−4.7729) + Humidity * “Agriculturalization, cubert” * (−14.7266) + “Agriculturalization, cubert” * 13.2576

Y1 = −0.00481198 + N514 * 0.0265466 + N2 * 0.980961
N2 = 0.0138847 + N620 * N3 * 0.0451508 + N3 * 0.943318
N3 = 0.000970565 + N18 * (−0.282403) + N4 * 1.28089
N4 = 0.0220096 + Humidity * (−0.0394223) + Humidity * N5 * 0.0786187 + N5 * 0.953831
N5 = −0.0232617 + N638 * 0.052051 + N6 * 0.98424
N6 = 0.00356283 + N241 * (−0.209952) + N8 * 1.20439
N8 = 0.0080356 + N436 * 0.105358 + N436 * N10 * 0.0162818 + N10 * 0.866102

N10 = −0.0119109 + N85 * (−0.745271) + N85 * N19 * (−0.0111308) + N19 * 1.77535

N19 = −0.00135155 + N23 * 0.523419 + N25 * 0.47869

N25 = −0.00311861 + N50 * 0.535619 + N54 * 0.469246

N54 = 0.0669671 + N292 * (−0.324799) + N292 * N127 * 0.0424681 + N127 * 1.17729

N127 = −0.218508 + N653 * 0.306807 + N653 * N196 * (−0.377646) + N196 * 1.30921

N196 = 0.048033 + N279 * 0.4376 + N279 * N309 * 0.0592005 + N309 * 0.429148

N309 = 0.357605 + N614 * (−0.367438) + N614 * N465 * 1.06443

N614 = 2.13068 + Industrialization * (−2.22574) + Industrialization * “GHG, cubert” * 1.69195 + “GHG, cubert” * (−1.35407)

N292 = 0.260264 + N458 * 0.135496 + N458 * N542 * 0.516371

N542 = 0.128607 + N616 * (−0.241592) + N616 * N657 * 2.04126 + N657 * (−0.257491)

N616 = 0.754351 + Humidity * 0.770033 + Humidity * Industrialization * (−0.758196) + Industrialization * (−0.591003)

N50 = 0.102502 + N187 * (−1.33182) + N187 * N131 * 0.0687939 + N131 * 2.10126

N131 = −0.139371 + N651 * 0.163243 + N651 * N151 * (−0.23263) + N151 * 1.22877

N151 = 0.120167 + N296 * 0.696481 + N296 * N343 * 0.117285

N343 = 0.3153 + N617 * (−0.291309) + N617 * N452 * 0.932382 + N452 * 0.0885783

N452 = 0.649364 + N573 * (−1.12207) + N573 * N730 * 3.41843 + N730 * (−1.07543)

N730 = 1.66577 + GHG * (−1.09508) + GHG * “Urbanization, cubert” * 1.02593 + “Urbanization, cubert” * (−1.14231)

N617 = 0.211867 + Industrialization * “Humidity, cubert” * (−1.27523) + “Humidity, cubert” * 1.2217

N651 = 0.0195714 + N687 * N727 * 1.50921

N727 = 0.434605 + GHG * Humidity * (−0.754392) + Humidity * 0.833651

N687 = −0.272094 + “Cloud Cover” * 0.186696 + “Agriculturalization, cubert” * 1.09405

N187 = 0.106756 + N296 * 0.735219 + N296 * N324 * 0.098902

N324 = 0.235074 + N489 * 0.0967665 + N489 * N511 * 0.466786 + N511 * 0.123464

N511 = 0.15282 + N610 * (−0.293723) + N610 * N657 * 2.16724 + N657 * (−0.32129)

N657 = −0.163406 + Urbanization * “Agriculturalization, cubert” * (−0.553424) + “Agriculturalization, cubert” * 1.3568

N489 = 0.464729 + N578 * (−0.633498) + N578 * N720 * 2.55981 + N720 * (−0.735621)

N578 = 0.452767 + Industrialization * (−0.384523) + Industrialization * Agriculturalization * (−1.2586) + Agriculturalization * 1.40132
N23 = −0.0984865 + “Cloud Cover” * 0.196673 + “Cloud Cover” * N38 * (−0.172477) + N38 * 1.08894
N85 = −0.211711 + N686 * 0.294314 + N686 * N133 * (−0.513431) + N133 * 1.39952
N133 = 0.0776637 + N284 * 0.201974 + N284 * N296 * 0.0791427 + N296 * 0.598162
N284 = 0.194561 + N458 * 0.216458 + N458 * N504 * 0.381381 + N504 * 0.137375
N504 = −0.0447996 + N610 * (−0.0484614) + N610 * N655 * 1.7614
N458 = 0.501261 + N575 * (−0.739195) + N575 * N720 * 2.77055 + N720 * (−0.817103)
N575 = −0.221672 + “Industrialization, cubert” * “Agriculturalization, cubert” * (−2.12201) + “Agriculturalization, cubert” * 2.74641
N686 = −0.387244 + ““Cloud Cover”, cubert” * 0.276394 + “Agriculturalization, cubert” * 1.0979
N436 = 0.263848 + N563 * (−0.386568) + N563 * N701 * 2.04954 + N701 * (−0.351149)
N701 = −0.0232911 + N736 * N741 * 1.61972
N736 = 0.76627 + “Cloud Cover” * 0.182758 + Urbanization * (−0.42151)
N563 = 0.176209 + N623 * (−0.309008) + N623 * N656 * 2.10829 + N656 * (−0.308615)
N656 = 0.669636 + Agriculturalization * 0.750562 + “GHG, cubert” * (−0.535757)
N623 = 0.887259 + Industrialization * (−8.44828) + Industrialization * “Industrialization, cubert” * 6.19274 + “Industrialization, cubert” * 1.7671
N241 = 0.0583008 + N279 * 0.425461 + N279 * N312 * 0.066718 + N312 * 0.417689
N312 = 0.367313 + N606 * (−0.421892) + N606 * N508 * 1.12389
N508 = −0.00994334 + N595 * N652 * 1.58184
N652 = −0.0509108 + Agriculturalization * 0.471044 + Agriculturalization * “Humidity, cubert” * 0.388478 + “Humidity, cubert” * 0.440383
N606 = 3.69317 + “GHG, cubert” * (−2.60444) + “GHG, cubert” * “Industrialization, cubert” * 2.78118 + “Industrialization, cubert” * (−3.55557)
N279 = 0.0532741 + N735 * (−0.0301097) + N735 * N441 * 1.46782
N735 = 0.229714 + Humidity * 0.432646 + ““Cloud Cover”, cubert” * 0.288117
N638 = 0.0141641 + N680 * N721 * 1.52108
N721 = 0.158114 + Urbanization * “Humidity, cubert” * (−0.608369) + “Humidity, cubert” * 0.980793
N680 = 0.332465 + Agriculturalization * “Agriculturalization, cubert” * 0.729505
N18 = −0.0354743 + N741 * 0.0685177 + N741 * N24 * 0.153028 + N24 * 0.885704
N24 = −0.657891 + N750 * 1.02642 + N750 * N38 * (−0.900139) + N38 * 1.57952

N38 = 0.0781012 + N181 * (−1.07816) + N181 * N94 * 0.0510328 + N94 * 1.90387
N94 = −0.163536 + N655 * 0.193581 + N655 * N138 * (−0.351437) + N138 * 1.3192
N138 = 0.0782218 + N269 * 0.209147 + N269 * N296 * 0.0788193 + N296 * 0.590242
N269 = 0.143185 + N441 * 0.302789 + N441 * N465 * 0.245907 + N465 * 0.247715
N441 = 0.55299 + N573 * (−0.796712) + N573 * N720 * 2.86554 + N720 * (−0.902075)
N720 = 2.97157 + “GHG, cubert” * (−2.4538) + “GHG, cubert” * “Urbanization, cubert” * 2.45935 + “Urbanization, cubert” * (−2.48814)
N573 = 0.717798 + Agriculturalization * 2.20452 + Agriculturalization * “Industrialization, cubert” * (−1.89856) + “Industrialization, cubert” * (−0.613445)
N655 = 0.483034 + Agriculturalization * 1.18677 + Agriculturalization * “Urbanization, cubert” * (−0.587182) + “Urbanization, cubert” * (−0.276075)
N181 = 0.109751 + N296 * 0.727471 + N296 * N342 * 0.102321
N342 = 0.332889 + N516 * (−0.133951) + N516 * N523 * 0.69279
N523 = 0.0661773 + N579 * N714 * 1.62708 + N714 * (−0.150355)
N714 = 1.89499 + Urbanization * (−1.59469) + Urbanization * “GHG, cubert” * 1.54033 + “GHG, cubert” * (−1.37012)
N579 = −0.210395 + Industrialization * “Agriculturalization, cubert” * (−1.37195) + “Agriculturalization, cubert” * 1.82388
N516 = 0.163616 + N610 * (−0.331841) + N610 * N660 * 2.23253 + N660 * (−0.340246)
N660 = −0.168855 + “Urbanization, cubert” * “Agriculturalization, cubert” * (−0.778985) + “Agriculturalization, cubert” * 1.67189
N610 = 0.21977 + “Humidity, cubert” * 2.01537 + “Humidity, cubert” * “Industrialization, cubert” * (−1.92366)
N296 = 0.469718 + N743 * (−0.756534) + N743 * N465 * 2.61029 + N465 * (−0.64721)
N465 = 0.00557396 + N580 * N653 * 1.63713 + N653 * (−0.0563088)
N653 = 0.116222 + Humidity * 0.32977 + Humidity * Agriculturalization * 0.197892 + Agriculturalization * 0.667174
N580 = 4.41525 + “Urbanization, cubert” * (−3.44149) + “Urbanization, cubert” * “Industrialization, cubert” * 3.63363 + “Industrialization, cubert” * (−4.30136)
N743 = 0.958278 + “Cloud Cover” * 0.178795 + “GHG, cubert” * (−0.544706)
N750 = 0.545008 + “Cloud Cover” * 0.191611
N741 = 0.177356 + “Humidity, cubert” * 0.639788
N620 = 1.47027 + GHG * (−0.708967) + GHG * Industrialization * 0.830996 + Industrialization * (−1.37382)
N514 = 0.218052 + N595 * (−0.351907) + N595 * N663 * 2.17634 + N663 * (−0.38105)
N663 = 0.412068 + GHG * (−0.290908) + Agriculturalization * 0.750794

N595 = 2.44412 + Industrialization * (−2.56496) + Industrialization * "Urbanization, cubert" * 2.07527 + "Urbanization, cubert" * (−1.72041)

Y1 = 0.000912284 + N10 * (−0.236446) + N2 * 1.23611
N2 = −0.0913949 + N610 * 0.0366909 + N3 * 0.996813
N3 = 0.233485 + N539 * (−0.0494118) + N539 * N4 * 0.0324951 + N4 * 0.865098
N4 = −0.59454 + N632 * 0.214537 + N632 * N5 * (−0.0464773) + N5 * 1.13128
N5 = 0.00652388 + N124 * (−0.2009) + N7 * 1.19851
N7 = 0.133341 + N476 * 0.0699185 + N476 * N14 * 0.0132894 + N14 * 0.837114
N14 = 0.0179172 + N261 * (−0.393524) + N22 * 1.38696
N261 = 0.646323 + N336 * 0.616107 + N336 * N437 * 0.0436097
N437 = 3.76913 + N528 * (−1.29574) + N528 * N575 * 0.819774 + N575 * (−1.32783)
N575 = 4.99451 + ""Cloud Cover", cubert" * "Agriculturalization, cubert" * 0.164831 + "Agriculturalization, cubert" * (−3.14845)
N476 = 3.18093 + N532 * (−1.0945) + N532 * N572 * 0.761897 + N572 * (−1.15113)
N532 = 5.76171 + Urbanization * (−2.71824) + Urbanization * Industrialization * 2.95646 + Industrialization * (−4.79223)
N610 = 3.80157 + GHG * (−0.954555) + Urbanization * (−1.17692)
N10 = −0.320112 + N632 * 0.120985 + N12 * 0.996364
N12 = 0.018013 + N263 * (−0.391075) + N22 * 1.38447
N22 = −0.00913906 + N49 * 0.629613 + N60 * 0.373738
N60 = 0.0195634 + N273 * (−0.782225) + N71 * 1.77505
N71 = −0.416434 + N572 * 0.180691 + N129 * 0.971967
N129 = 0.487786 + N531 * N256 * 0.0721023 + N256 * 0.599209
N256 = 0.62175 + N336 * 0.649018 + N336 * N358 * 0.0358407
N358 = 3.72969 + N529 * (−1.35137) + N529 * N562 * 0.836429 + N562 * (−1.30216)
N562 = 9.24043 + "Urbanization, cubert" * (−5.5439) + "Urbanization, cubert" * "Agriculturalization, cubert" * 5.11643 + "Agriculturalization, cubert" * (−6.95207)
N531 = 7.70227 + Industrialization * (−7.03986) + Industrialization * "Urbanization, cubert" * 4.9286 + "Urbanization, cubert" * (−4.37478)
N572 = 4.7883 + Agriculturalization * (−1.89445) + "GHG, cubert" * (−1.50313)
N273 = 0.617194 + N329 * 0.642699 + N329 * N378 * 0.0383475
N378 = 3.6174 + N527 * (−1.21621) + N527 * N571 * 0.797175 + N571 * (−1.28971)
N571 = 4.6856 + GHG * (−2.07432) + GHG * Agriculturalization * 2.27468 + Agriculturalization * (−3.00763)
N49 = 0.286538 + N251 * (−2.22814) + N251 * N124 * 0.0114168 + N124 * 3.08353
N124 = −0.362279 + N556 * 0.170092 + N161 * 0.962715
N161 = 0.258232 + N539 * N271 * 0.0529781 + N271 * 0.745366
N271 = 0.549833 + N329 * 0.69147 + N329 * N351 * 0.0311011

N351 = 3.5387 + N529 * (−1.26751) + N529 * N561 * 0.804668 + N561 * (−1.23014)
N561 = 6.92918 + Urbanization * (−3.61433) + Urbanization * “Agriculturalization, cubert” * 3.22942 + “Agriculturalization, cubert” * (−4.77791)
N529 = 8.691 + GHG * (−4.39712) + GHG * “Industrialization, cubert” * 4.65861 + “Industrialization, cubert” * (−7.36363)
N539 = 4.33747 + Industrialization * (−3.22979)
N556 = 1.28706 + N565 * N580 * 0.318224 + N580 * (−0.352446)
N580 = −0.128493 + N622 * N633 * 0.38399
N633 = 3.83736 + “Cloud Cover” * (−0.0445428) + “GHG, cubert” * (−1.45554)
N565 = −0.127714 + N578 * N624 * 0.384184
N624 = 3.32005 + Urbanization * (−1.27716) + Urbanization * “Humidity, cubert” * 0.173011
N251 = −0.224562 + N284 * 0.97496 + N558 * 0.107361
N558 = 1.2928 + N566 * N581 * 0.31841 + N581 * (−0.355153)
N581 = −0.132038 + N622 * N635 * 0.384468
N635 = 3.813 + “GHG, cubert” * (−1.4528)
N622 = 3.49842 + “Cloud Cover” * (−0.350935) + “Cloud Cover” * Urbanization * 0.606762 + Urbanization * (−1.45787)
N566 = −0.123683 + N578 * N625 * 0.383617
N625 = 3.31976 + Urbanization * (−1.15062)
N578 = 3.65737 + Agriculturalization * (−2.04893) + Agriculturalization * ““Cloud Cover”, cubert” * 0.229736
N284 = 0.542125 + N329 * 0.693798 + N329 * N359 * 0.0312935
N359 = 4.86748 + N507 * (−1.83567) + N507 * N609 * 1.04639 + N609 * (−1.79695)
N609 = 4.45273 + Urbanization * (−1.17578) + “GHG, cubert” * (−1.49953)
N507 = 14.7117 + “Industrialization, cubert” * (−13.3758) + “Industrialization, cubert” * “Agriculturalization, cubert” * 11.6047 + “Agriculturalization, cubert” * (−11.344)
N329 = 3.59122 + N528 * (−1.17164) + N528 * N570 * 0.770471 + N570 * (−1.2551)
N263 = 0.642228 + N336 * 0.618588 + N336 * N439 * 0.0433212
N439 = 3.79017 + N528 * (−1.30399) + N528 * N576 * 0.821822 + N576 * (−1.33276)
N576 = 4.994 + “Agriculturalization, cubert” * (−3.0251)
N528 = 13.6166 + “Urbanization, cubert” * (−9.16474) + “Urbanization, cubert” * “Industrialization, cubert” * 9.52197 + “Industrialization, cubert” * (−12.456)
N336 = 3.57219 + N527 * (−1.17136) + N527 * N570 * 0.771761 + N570 * (−1.25125)
N570 = 9.88428 + “GHG, cubert” * (−6.48236) + “GHG, cubert” * “Agriculturalization, cubert” * 6.59649 + “Agriculturalization, cubert” * (−8.01074)

N527 = 9.39641 + Urbanization * (−5.4188) + Urbanization * “Industrialization, cubert” * 5.51995 + “Industrialization, cubert” * (−8.00815)
N632 = 3.20034 + GHG * (−0.923104) + “Cloud Cover” * (−0.0391478)
Y1 = 0.0013813 + N351 * (−0.0778767) + N9 * 1.0707

N9 = 0.000531352 + N92 * (−0.506843) + N15 * 1.50408
N15 = −0.000435491 + N37 * 0.528961 + N42 * 0.473303
N42 = 0.0031165 + N404 * (−0.163367) + N61 * 1.14716
N61 = −0.00186673 + N105 * 0.614611 + N149 * 0.395094
N149 = 0.0202959 + N268 * 0.372651 + N268 * N272 * 0.39191 + N272 * 0.414902
N272 = 0.000117684 + N591 * N589 * 5.16712
N589 = 0.138906 + N623 * (−0.743052) + N623 * N687 * 8.86597 + N687 * (−0.685942)
N623 = 0.383793 + GHG * (−0.146582) + GHG * Industrialization * 0.193695 + Industrialization * (−0.334879)
N268 = 0.00326879 + N485 * 0.0623921 + N485 * N681 * 4.77561
N681 = 0.0657757 + N700 * N710 * 4.6462 + N710 * (−0.241886)
N710 = 0.400164 + GHG * (−0.251062) + GHG * “Urbanization, cubert” * 0.259619 + “Urbanization, cubert” * (−0.238085)
N700 = 0.153737 + GHG * (−0.0483166) + “Cloud Cover” * 0.124412
N485 = 0.0017953 + N594 * N613 * 5.11577
N613 = 0.82824 + “Urbanization, cubert” * (−0.467403) + “Urbanization, cubert” * “Industrialization, cubert” * 0.457201 + “Industrialization, cubert” * (−0.721276)
N594 = 0.2213 + Humidity * 0.267458 + “Agriculturalization, cubert” * (−0.201021)
N105 = −0.0553934 + “GHG, cubert” * 0.072871 + “GHG, cubert” * N260 * (−0.875541) + N260 * 1.66072
N404 = 0.0485426 + N490 * 0.246961 + N490 * N588 * 2.23882
N588 = 0.00770761 + N624 * N674 * 4.95861
N674 = 0.278649 + “Cloud Cover” * 0.126821 + “Agriculturalization, cubert” * (−0.2)
N490 = 0.133842 + N580 * (−0.759913) + N580 * N691 * 9.1897 + N691 * (−0.700776)
N37 = −0.00103489 + N98 * 0.601049 + N104 * 0.404332
N104 = −0.00405066 + N260 * 0.330802 + N143 * 0.690256
N143 = 0.0338761 + N587 * (−0.0854863) + N587 * N252 * 0.766119 + N252 * 0.731393
N587 = 0.131477 + N624 * (−0.706653) + N624 * N687 * 8.69188 + N687 * (−0.650264)
N687 = 0.481008 + Urbanization * (−0.262518) + Urbanization * “Agriculturalization, cubert” * 0.254861 + “Agriculturalization, cubert” * (−0.335394)
N624 = 0.488805 + Industrialization * (−0.477014) + Industrialization * “GHG, cubert” * 0.318553 + “GHG, cubert” * (−0.237663)

N260 = 0.00421025 + N592 * N586 * 5.05923
N98 = −0.0126773 + N518 * (−0.21031) + N518 * N128 * (−0.384801) + N128 * 1.37771
N128 = 0.0100465 + N262 * 0.577902 + N262 * N496 * 0.476673 + N496 * 0.248114
N496 = 0.0266674 + N577 * N632 * 4.82113 + N632 * (−0.0774384)
N632 = −0.0014053 + N673 * N709 * 5.23718
N673 = 0.190965 + “Cloud Cover” * 0.12819 + Agriculturalization * (−0.126921)
N577 = −0.0492284 + N615 * 0.344872 + N615 * N619 * 2.58665 + N619 * 0.404258
N619 = 0.00178466 + “GHG, cubert” * (−0.112994) + “Humidity, cubert” * 0.379438
N615 = 0.624428 + GHG * (−0.319176) + GHG * “Industrialization, cubert” * 0.357416 + “Industrialization, cubert” * (−0.542914)
N518 = 0.00694672 + N599 * 0.0336049 + N599 * N601 * 4.7947
N601 = 0.187816 + ““Cloud Cover”, cubert” * 0.377915 + ““Cloud Cover”, cubert” * “Industrialization, cubert” * (−0.266639) + “Industrialization, cubert” * (−0.171082)
N599 = −0.0771588 + “Humidity, cubert” * 0.586649 + “Humidity, cubert” * “Agriculturalization, cubert” * (−0.286211)
N92 = −0.00197641 + N127 * 0.600306 + N158 * 0.409969
N158 = 0.0471536 + N691 * (−0.19023) + N691 * N252 * 1.71552 + N252 * 0.60071
N252 = 0.19693 + N469 * (−1.12559) + N469 * N706 * 11.2348 + N706 * (−1.05154)
N706 = −1.51496e − 14 + N709 * 1
N709 = 0.295452 + GHG * (−0.133605) + GHG * Urbanization * 0.155814 + Urbanization * (−0.148758)
N469 = 0.00169998 + N592 * N595 * 5.1215
N595 = 0.930696 + “Industrialization, cubert” * (−0.813687) + “Industrialization, cubert” * “Agriculturalization, cubert” * 0.627764 + “Agriculturalization, cubert” * (−0.643786)
N592 = 0.00399528 + “Cloud Cover” * 0.131232 + Humidity * 0.269625
N691 = 0.426597 + Agriculturalization * (−0.308349) + Agriculturalization * “Urbanization, cubert” * 0.241091 + “Urbanization, cubert” * (−0.226206)
N127 = 0.165847 + N713 * (−0.866488) + N713 * N262 * 9.99158 + N262 * (−0.916245)
N262 = 0.00537939 + N591 * N586 * 5.02471
N586 = 0.194155 + N622 * (−0.998655) + N622 * N689 * 10.2155 + N689 * (−0.978963)
N622 = 0.374135 + Industrialization * (−1.00778) + Industrialization * “Industrialization, cubert” * 0.751614
N591 = −0.0731644 + Humidity * 0.27077 + ““Cloud Cover”, cubert” * 0.191228
N713 = 0.2584 + “GHG, cubert” * (−0.0884291)
N351 = 0.00463127 + N484 * 0.165175 + N484 * N680 * 4.18328

Table 5.7 Table showing the input and output of the climate model for predicting the vulnerability of the considered watersheds

River	Scenario	Time slabs	GHG	Cloud cover	Humidity	Urbanization	Industrialization	Agriculturalization	Rainfall	ET	Q	F	I	W	S	WQI
Nile	A2	2010–2030	0.150	0.300	0.250	0.750	0.650	0.850	0.097	9.903	0.089	0.075	13.327	0.535	1.846	0.075
		2031–2060	0.250	0.200	0.350	0.800	0.750	0.800	0.116	8.204	0.103	0.079	12.633	0.458	1.681	0.079
		2061–2100	0.500	0.100	0.450	0.900	0.860	0.700	0.157	6.162	0.134	0.082	12.299	0.364	1.489	0.082
	B2	2010–2030	0.100	0.100	0.450	0.750	0.650	0.800	0.109	8.851	0.103	0.094	9.910	0.550	1.914	0.094
		2031–2060	0.200	0.200	0.500	0.700	0.600	0.800	0.154	6.165	0.140	0.115	8.185	0.605	1.955	0.115
		2061–2100	0.400	0.300	0.500	0.700	0.560	0.800	0.214	4.697	0.188	0.124	7.940	0.611	1.919	0.124
Amazon	A2	2010–2030	0.250	0.500	0.700	0.450	0.450	0.500	0.340	2.897	0.300	0.250	3.931	0.734	2.738	0.250
		2031–2060	0.350	0.400	0.600	0.400	0.400	0.600	0.332	3.057	0.293	0.209	4.792	0.803	2.712	0.209
		2061–2100	0.400	0.300	0.500	0.550	0.500	0.700	0.248	4.134	0.218	0.139	7.003	0.641	2.201	0.139
	B2	2010–2030	0.150	0.300	0.500	0.400	0.500	0.500	0.222	4.547	0.199	0.171	5.728	0.620	2.738	0.171
		2031–2060	0.200	0.400	0.700	0.500	0.600	0.500	0.260	3.653	0.230	0.199	4.744	0.576	2.356	0.199
		2061–2100	0.220	0.450	0.850	0.650	0.700	0.600	0.255	3.712	0.223	0.201	4.780	0.587	1.979	0.201
Mississippi	A2	2010–2030	0.200	0.400	0.750	0.800	0.500	0.500	0.268	3.530	0.237	0.211	4.591	0.589	2.322	0.211
		2031–2060	0.300	0.350	0.650	0.900	0.600	0.700	0.213	4.463	0.188	0.152	6.609	0.560	1.883	0.152
		2061–2100	0.450	0.300	0.550	0.900	0.600	0.700	0.221	4.495	0.192	0.127	7.846	0.504	1.821	0.127
	B2	2010–2030	0.100	0.250	0.550	0.800	0.700	0.600	0.143	6.466	0.130	0.127	7.351	0.470	1.962	0.127
		2031–2060	0.150	0.300	0.650	0.800	0.700	0.700	0.169	5.334	0.151	0.144	6.717	0.548	1.867	0.144
		2061–2100	0.170	0.500	0.870	0.800	0.700	0.800	0.224	4.121	0.197	0.196	5.280	0.679	1.797	0.196
Yangtze	A2	2010–2030	0.300	0.500	0.890	0.500	0.600	0.600	0.329	3.048	0.286	0.236	3.935	0.687	2.200	0.236
		2031–2060	0.350	0.300	0.780	0.600	0.700	0.800	0.236	4.126	0.206	0.162	6.083	0.631	1.791	0.162
		2061–2100	0.400	0.200	0.700	0.700	0.800	0.870	0.195	4.934	0.167	0.128	7.697	0.555	1.560	0.128
	B2	2010–2030	0.200	0.200	0.700	0.500	0.600	0.550	0.230	4.123	0.205	0.173	5.245	0.573	2.307	0.173
		2031–2060	0.300	0.400	0.800	0.500	0.650	0.650	0.275	3.551	0.241	0.195	4.911	0.637	2.062	0.195
		2061–2100	0.400	0.600	0.920	0.400	0.500	0.560	0.437	2.393	0.377	0.286	3.065	0.785	2.474	0.286
Yensini	A2	2010–2030	0.100	0.600	0.800	0.600	0.650	0.600	0.248	3.636	0.220	0.226	4.241	0.665	2.171	0.226
		2031–2060	0.200	0.500	0.700	0.650	0.650	0.600	0.237	3.982	0.209	0.187	5.278	0.589	2.070	0.187
		2061–2100	0.300	0.400	0.650	0.700	0.730	0.700	0.211	4.562	0.184	0.149	6.698	0.543	1.799	0.149
	B2	2010–2030	0.050	0.300	0.650	0.600	0.650	0.600	0.176	5.253	0.157	0.166	5.656	0.590	2.216	0.166
		2031–2060	0.070	0.500	0.700	0.600	0.650	0.600	0.210	4.286	0.187	0.197	4.980	0.631	2.196	0.197
		2061–2100	0.100	0.500	0.800	6.000	0.560	0.500	−0.274	8.153	-0.104	-0.043	15.684	-0.543	1.328	-0.043

(continued)

Table 5.7 (continued)

River	Scenario	Time slabs	GHG	Cloud cover	Humidity	Urbanization	Industrialization	Agriculturalization	Rainfall	ET	Q	F	I	W	S	WQI
Ganges	A2	2010–2030	0.250	0.500	0.760	0.700	0.670	0.650	0.247	3.876	0.217	0.188	5.307	0.601	1.946	0.188
		2031–2060	0.350	0.400	0.700	0.800	0.780	0.700	0.216	4.504	0.186	0.150	6.866	0.516	1.675	0.150
		2061–2100	0.400	0.400	0.700	0.900	0.870	0.800	0.200	4.880	0.170	0.140	7.877	0.513	1.470	0.140
	B2	2010–2030	0.200	0.300	0.700	0.700	0.670	0.650	0.202	4.566	0.180	0.160	5.984	0.561	1.969	0.160
		2031–2060	0.220	0.450	0.800	0.600	0.560	0.500	0.297	3.242	0.261	0.227	4.160	0.617	2.352	0.227
		2061–2100	0.250	0.550	0.860	0.500	0.450	0.500	0.387	2.560	0.337	0.293	3.118	0.780	2.687	0.293

N680 = 0.0417504 + N702 * N708 * 4.03635
N708 = 0.404222 + Urbanization * (−0.277415) + Urbanization * “GHG, cubert” * 0.27457 + “GHG, cubert” * (−0.233332)
N702 = 0.120078 + “GHG, cubert” * (−0.0800043) + ““Cloud Cover”, cubert” * 0.177336
N484 = 0.000111764 + N580 * (−0.139388) + N580 * N689 * 5.92649
N689 = 0.689276 + “Urbanization, cubert” * (−0.455527) + “Urbanization, cubert” * “Agriculturalization, cubert” * 0.469057 + “Agriculturalization, cubert” * (−0.557149)
N580 = 0.128332 + Humidity * 0.384407 + Humidity * Industrialization * (−0.250992) + Industrialization * (−0.110056)

5.2 Comparison with Other Similar Studies

In the present study, impervious area and precipitation were determined as the most and second most important parameter, respectively, among the factors considered in the present investigation. This result was seconded by Thomas et al. (2007). In that study authors tried to analyse the adaptation of farmers to climate change. In this regard they have used eight different factors and among the eight factors, precipitation was determined as the most important factor. In case of climate change impact, the selected regions are more vulnerable to the climate change in A2 scenario than in B2 scenario (Table 5.8). This result was also found by Arnell (2004). The author of the paper analyses the climate change impact and hazards due to the climate change on various aspects including water availability under different socio-economic scenarios. In the study, also A2 scenario is found to affect more severely than B2 scenario. The results from the present investigation also yielded that the Mississipi River will be affected worse than the other rivers compared in the study in the time slab 2061–2100 under A2 scenario, whereas in B2 scenario of the same time slab the region will have minimum vulnerability. This result was also commended by the results from the study of Nijsen et al. (2001) where it was found that the tropical and mid-latitude rivers like the Mississippi River in the US will have decreased annual stream flow. This condition will reduce the overall availability of water in the region. Smith (2013) also stressed on the vulnerable condition of the Mississippi River and found high probability of disasters related to extreme water events. Palmer et al. (2008) in their study have found that extensive mitigative measures have to be implemented to avoid climate-related disasters in controlled rivers like Mississipi compared to free-flowing rivers (Table 5.7).

Table 5.8 Table showing the impact of climate change on the water availability with the help of the vulnerability index

River	Scenario	Time slabs	Index	Rank
Nile	A2	2010–2030	0.627976	14
		2031–2060	0.810516	5
		2061–2100	0.946429	2
	B2	2010–2030	0.457341	26
		2031–2060	0.14881	35
		2061–2100	0.30754	32
Amazon	A2	2010–2030	0.506944	24
		2031–2060	0.518849	21
		2061–2100	0.541667	20
	B2	2010–2030	0.509921	23
		2031–2060	0.680556	11
		2061–2100	0.599206	17
Mississippi	A2	2010–2030	0.581349	19
		2031–2060	0.706349	10
		2061–2100	1	1
	B2	2010–2030	0.724206	8
		2031–2060	0.657738	12
		2061–2100	0	36
Yangtze	A2	2010–2030	0.335317	31
		2031–2060	0.349206	29
		2061–2100	0.624008	16
	B2	2010–2030	0.763889	7
		2031–2060	0.516865	22
		2061–2100	0.342262	30
Yensini	A2	2010–2030	0.376984	28
		2031–2060	0.59623	18
		2061–2100	0.71131	9
	B2	2010–2030	0.39881	27
		2031–2060	0.304563	33
		2061–2100	0.902778	4
Ganges	A2	2010–2030	0.62996	13
		2031–2060	0.907738	3
		2061–2100	0.804563	6
	B2	2010–2030	0.625	15
		2031–2060	0.47123	25
		2061–2100	0.27877	34

5.3 Scientific Implications

The vulnerability index in the present study was developed in such a manner that both temporal variation and the most important parameters in regard to watershed vulnerability can be included. In the earlier indices both of these were the major cause for either overestimating or under predicting the actual vulnerabilities.

This indicator can become a useful tool for management and strategic decision-making as it can depict the need of developmental activities in the watershed to mitigate the impacts of climate change.

The indicator can become a tool of any decision support system and if linked with predictive modelling frameworks may provide useful information of both the present and the future scenario. The indicator can also be used as an early warning system for alerting the planners of the watershed about a forthcoming vulnerable situation.

5.4 Assumptions/Limitations

The major limitation of the study is that it does not consider life and policy issues of the people living in the watersheds. The demand parameters may somewhat solve this problem but still more study can be conducted to provide a detailed solution.

The versatility of the indicator is also required to be tested by applying the same into other watersheds as well.

The impact of scale has to be verified by using the indicator to represent the status of the watershed for different scales.

References

Arnell, N. W. (2004). Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environmental Change, 14*(1), 31–52.

Nijssen, B., O'Donnell, G. M., Hamlet, A. F., & Lettenmaier, D. P. (2001). Hydrologic sensitivity of global rivers to climate change. *Climatic Change, 50*(1–2), 143–175.

Palmer, M. A., Reidy Liermann, C. A., Nilsson, C., Flörke, M., Alcamo, J., Lake, P. S., & Bond, N. (2008). Climate change and the world's river basins: Anticipating management options. *Frontiers in Ecology and the Environment, 6*(2), 81–89.

Smith, K. (2013). *Environmental Hazards: Assessing Risk and Reducing Disaster*. Routledge.

Thomas, D. S., Twyman, C., Osbahr, H., & Hewitson, B. (2007). Adaptation to climate change and variability: Farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change, 83*(3), 301–322.

Chapter 6
Conclusion

Abstract The present investigation is an attempt to represent status of the watershed with the help of an indicator so that climatic impact on watersheds can be adjudged both cognitively and objectively. Although the study showed reliability and encouraged the present authors for further applications, few limitations were also identified. The importance of the parameter will change with changing of MCDM method and also the temporal variation of the parameters were ignored. This two limitations can be overcome by the introduction of uniformity while rating the watersheds. The temporal variations can be removed by the introduction of some time parameters in the objective function.

Keywords Limitations · Sensitive · Model reliability

The present investigation attempted to develop an index which will represent the vulnerability of watershed in sustenance of living being like human and animal. Although there are various indices which represent watershed vulnerability but all those indicators are subjective in nature, absolutely compared and uniformly weighted.

The present study attempted to remove this shortcomings of the existing indicators by introducing objective methods like MCDM for comparison and cognitive method like ANN for prediction of the vulnerability in such a manner that no parameters are given over or under importance.

The indicator was applied to predict the vulnerability of six different watersheds collected from different parts of the World. The indicator is also used to predict the status of the watersheds in the time of climate change.

The climatic data was collected from PRECIS RCM.

6.1 Summary

Figure 6.1 depicts an overall view of the study, methods applied and the results achieved. The AHP MCDM method was used for finding the weights of importance of each of the parameters.

U. Roy and M. Majumder, *Vulnerability of Watersheds to Climate Change Assessed by Neural Network and Analytical Hierarchy Process*, SpringerBriefs in Water Science and Technology, DOI 10.1007/978-981-287-344-6_6

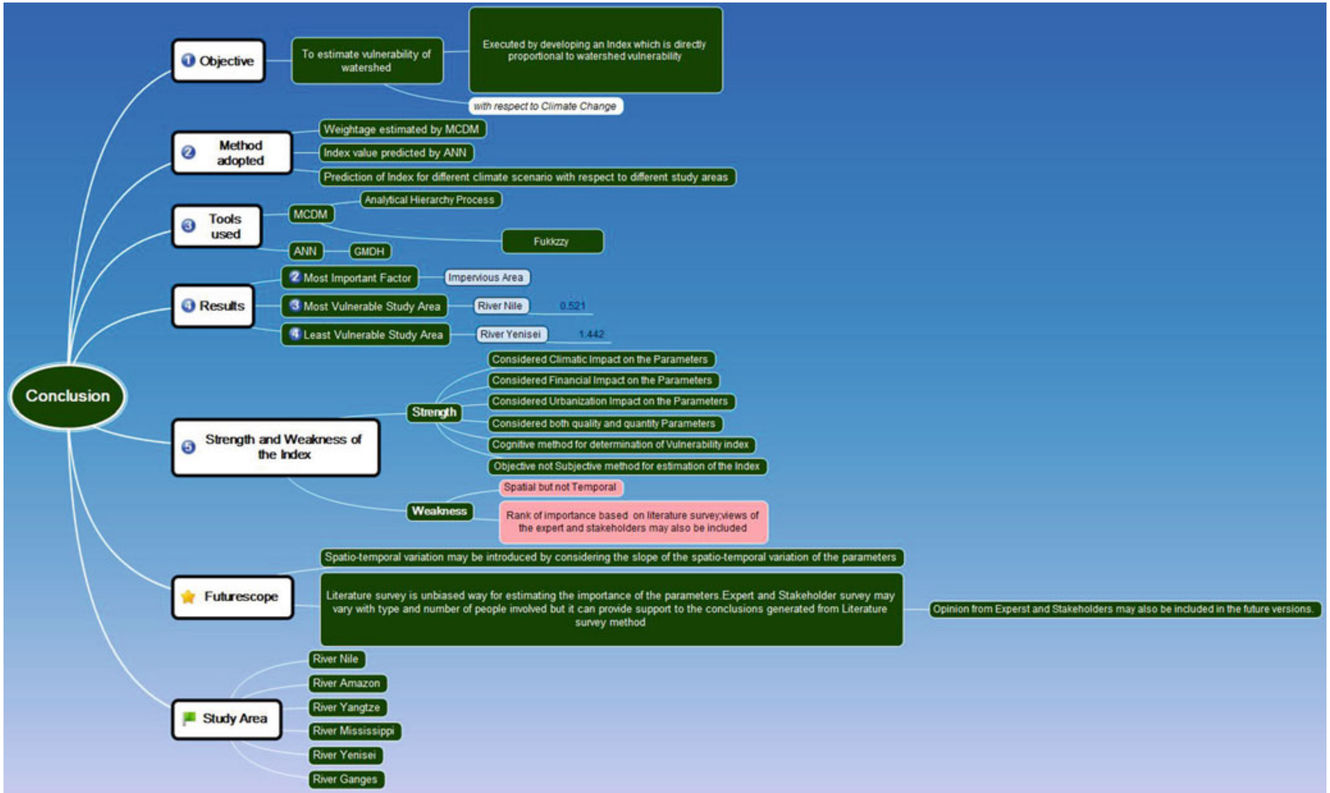


Fig. 6.1 Figure showing a schematic representation of the conclusions found from the present investigation

ANN method GMDH is used to predict the overall value of the indicator once the magnitude of the input parameters is given. This cascading of MCDM and ANN method provides an objectivity and cognitivity to the indicator which enhance the reliability of the media output.

In total nine parameters were considered. All the parameters are compared with each other based on climatic, change in urban population and financial impacts that may takes place due to the change in regular climate pattern of the watersheds.

6.2 Limitations

The parameters of the indicator were spatially varied. But its temporal variation was not considered as it may increase the complexity of data collection. Although water quality was included, the importance of all the parameters were collected from the literature surveys only. This may be not enough to standardize the importance of each parameter over the other which may yield somewhat erroneous representation of the situation.

6.3 Future-Scope

As described in the earlier section, temporal variation may be included to make the index more applicable and robust. The slope of the curve generated from the temporal data of the parameter may be used instead of discrete value that is being entered in the present case.

The views from the expert and stakeholders may be included but this will also make the index preferential where the weights may change with the number and type of experts/stakeholders used. An overall and equivalent consensus in this regard may be not possible at all.

Some maps or graphical tool may be developed which can create spatial representations of the watersheds based on vulnerability towards the climate change.