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Surface Water Resources, Climate Change and Simulation Modeling

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Abstract

In the wake of changing climate the present water crisis seems to tighten its hold on the Mankind hence water resources estimation is integral part of planning, development and management of water resources of the country and the estimation of water resource is based on several hydrological and meteorological parameters. Rainfall is the main source of the ground and surface water resources. Recently due to anticipated climate change it is projected that spatial and temporal pattern of rainfall in different part of the country will be change and there will be increase in intensity of rainfall greater monsoon variability. This unprecedented change is expected to have severe impact on the on the water resource and finally on water resource estimation for future planning and management. Apart from climate change, both the ever increasing population and the rapidly changing land use patterns have left the major river basins of the India in a bleak uncertainty to keep up the required runoff. For planning and management, the climate and the hydrological modellers have begun working out runoff projections. During recent years, the Global Climate Models (GCMs) and Regional Climate Models (RCMs) driven hydrological models are in frequent use to draw such projections. But the projections have been often found to lack of reliability. Very recently, there is another emerging field of multi-model ensembles that has added feather to cap of the climate modeling community but this field is yet to be tried in many of the basin runoff-studies especially in the Indian perspective. There is a dire need for more research input assessing the future runoff as far as the Indian River basins are concerned. The climate models are being improved day by day so are the hydrological models. The multi-model ensembles are expected to bring out more reliability in the model outputs regarding the future runoff regimes of the basins than that could be brought about using individual models. The present study is a brief reviewof the model-based projections made for the some of the major river basins of the world. This attempt also seeks to bring forth the basin wise state-of-the-art research activities of such a kind so that the unexplored horizons of model based hydrological research could be taken up as newer research challenges like eg. in India there hasn't yet been much basin scale studies conducted using multi-model ensembles. Therefore it is suggested that detailed studies to be taken up to assess the impact of climate change on the

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various parameters involved in estimation of water resources and asses water resource keeping in view the climate change for more realistic future planning and integrated water resource management.

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Keywords:Basin-runoff; Climate Change; Climate model;Multi-model ensembles; Surface water resources

1. Climate Change and hydrological cycle

It is now agreed that the changing climate would bring changes into hydrological parameters like temperature and precipitation, evapotranspiration (Jain and Kumar, 2012). These parameters are in common when it comes to whole plethora of climatic variables apart from humidity, pressure etc. which are not in common. The projections regarding the trends of these parameters have proven to be of help estimating the impact of climate change on hydrology in the future both at global and at regional scales. As the water resources are inextricably linked with climate, the global Climate Change has serious implications on them (Bates et al., 2008; Ghosh and Mishra, 2010) and therefore, has lead to the vulnerable state of the water resources worldwide.The warmer climate has already altered the hydrologic cycle. Eventually, the magnitude as well as the nature of run-off for various river basins across the world too has changed (Fig.1). Thus the changing temperature and precipitation conditions are key drivers to the changing climate conditions (Mall et al., 2006).

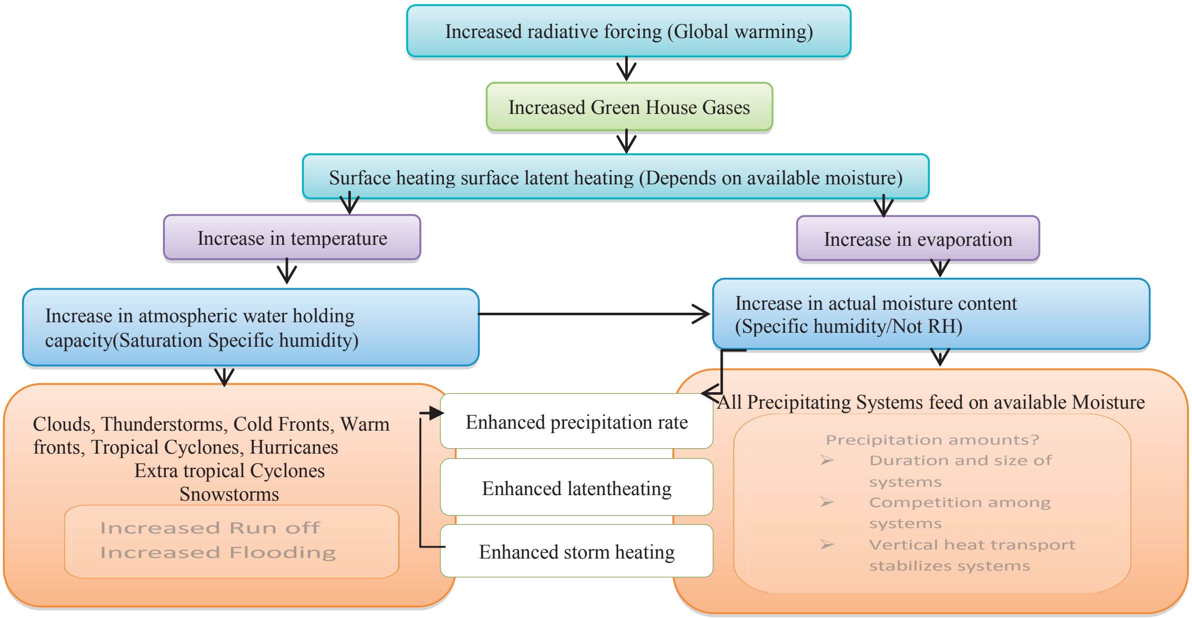

Fig 1:The impact of higher concentration of GHGs in the atmosphere cascading down to changed precipitation regimes along with the temperature changes (Source: Mall et al., 2006).

The drivers of the changing climate affecting the hydrological system are of two kinds: climatic (e.g. Rainfall) and non-climatic (e.g. Land-use pattern). As far as the climatic drivers are concerned they have already been discussed before. To name thenon-climatic drivers, the Green House Gas (GHGs) emission (Fig.1) and land-use changes, are the major anthropogenic activities that cannot escape a mention. These are the 'Man- made Climate Changes' which have actually pushed the global hydrological dynamics to an utter undesirability.

The Working Group I AR5 Summary for Policymakers emphasised the high probability of increase in the events of heavy precipitation globally and especially over the mid-latitude land masses and over wet tropical regions by the end of 21st century. Keeping at par with the development of IPCC's emission scenario and advancement in Climate Science research, the hydrological research too is trying out various permutations and combinations of different hydrological models being driven by improved climate models under different scenarios. The present work is an effort to compile state-of-the-art of basin level water resources in the backdrop of Climate Change using simulation studies of the major rivers across the world with a brief discussion on the scope of use of ensemble modeling in the same sector in India.

2. Water resources and Climate Change

The intensification of the global Hydrological Cycle has driven major surface freshwater resources eg. the rivers and the lakes to local and regional scale alterations in their water balances. To site some examples are the cases of the rivers like the Ganga(Gosain et al., 2011) and the Mississippi (Jha et al., 2007) which have shown increase in mean seasonal/annual flow whereas, some are struggling to maintain the sufficient base flow during dry seasons eg. Indus (Arora and Boer, 2001).

It is already suspected that the impact of climatic change would be felt rather more severely by the developing countries like India in near future(Mall et al.2006, Mall et al. 2007). The developing countries are more vulnerable to the climatic adversities hurled at due to the fact that their economies being largely dependent on agriculture. As far as India is concerned,it is already running under stress trying hard to fulfill the demands of current for energy, freshwater and food. It seems that meeting the demands associated with the projected population increase is a great management challenge for the government.

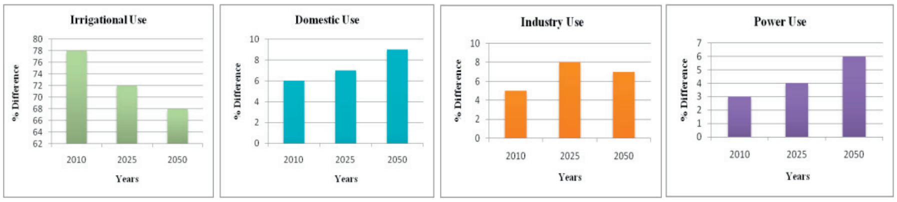

Figure 2: % Difference in Low and High Water demand (Projected) in Major Use Category for India (Source: Mall 2013).

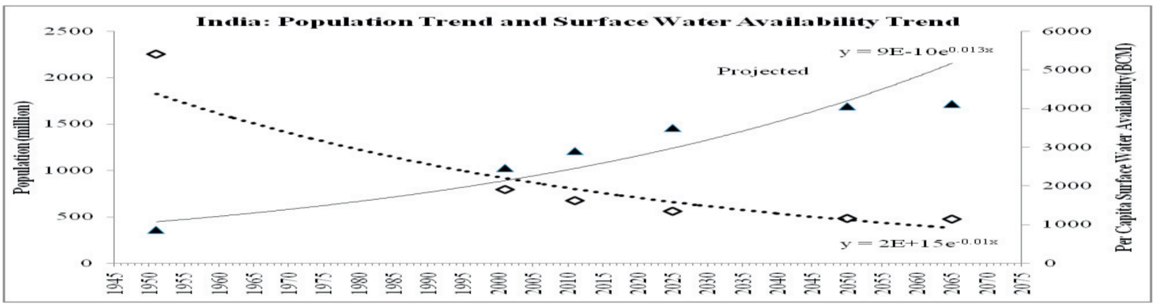

Figure 3: Observed and Projected Trends in Population growth and Surface Water Availability for India. (Source: Jain 2011)

As per the projections for 2050 the irrigated area from surface water is would rise up to 70.4 million hectares from the 2010 count of 36.75 million hectares Jain (2011) whereas ironically the future per-capita surface water availability is already showing decreasing trend (Fig. 3). As mentioned earlier the largest sector in terms of water consumption in India is agriculture sector (Fig.2). Thus these counts for the need of surface water to irrigate the agricultural landshould be actually given serious attention. To make situations worse, most of the rivers across the world, our major surface water sources,have already begun to experience strong spatio-temporaluncertainties in the magnitude of their runoffs. The projections by Arora and Boer (2001) are concerned keeping aside the limitations arising due to the inaccuracies of the coarse spatial resolution of General Circulation Models (GCMs), the middle-and high-Latitude Rivers are to see decrease in the annual amplitude and phase of stream-flow cycle. On the other hand, the Lower-Latitude Rivers are projected to see only a negligible reduction in the annual discharge. But Nijssen et al. (2001) reported that it is the tropical to mid-latitude rivers who would suffer a reduction in annual stream-flow whereas; the high-latitude Rivers would see an increase in the annual runoff. In high-northern latitude Rivers the runoff is supposed to increase. Whereas, Wetherald and Manabe (2002) found that except in case of some tropical rivers i.e. the Amazon and Ganges where runoff is projected to increase substantially, most other tropical and middle latitude rivers are projected to undergo small percentage of changes, both positive and negative, in their simulated runoffs.Jones (2011) confirmed all these findings by underscoring the fact that as atmosphere warms up, one of the most probable alarming consequences of climate warming would be the likeliness of change in streamflows. There is a good concensus fromArora and Boer (2001), Wetherald and Manabe (2002), Jha et al. (2007), Yang et al. (2002), Ye et al. (2009), Costard et al. (2007), Bormann (2010), Gain et al. (2011) and Ghosh and Dutta (2012) that Bramhaputra, Danube, Lena and Mississipi are to experience increased runoff. And yet there are many riverseg. the Ganga, Indus and Nile whose future runoffs do not have any clear concensus from the researchers that is Beyene et al. (2007),Soliman et al. (2009) and Taye et al. (2010).

The above description on the fate of the runoff of the major rivers across world highlights the variability in the runoff projections drawn using the modelling approach. Starkly the same basins are projected to undergo both the states of high and low runoff based on the simulations from different models eg. Danube and Amazon River basins as reported by Arora and Boer (2001),Wetherald and Manabe (2002),Mauser and Bach (2009)and Davidson et al. (2012). Reasons may lie in the major factors that govern the runoff in these river basins. As in case of the Amazon e.g. it is the huge expanse of Amazon forests along the River banks whose rate of evapotranspiration plays the key role in deciding the runoff wherein, for the Lena, it is the permafrost whose melting rate governs the discharge.

3. Simulating the Climate Change impact on the water resources: a state-of-the-art

Especially, the past 20 years have played a major role in the advancement of simulation modeling science. As perIPCC(2013) the climate models are undergoing the rigorous process of improvement sinceIPCC(2007). Nevertheless, after all such advancements the simulation models need a long way to go to simulate regional precipitation and cloud and aerosol interactions properly. As far as the involvement of these climate models to carry out the hydrological studies is related both the Regional Climate Models (RCMs) as was studied by Wang et al. (2004) and Block (2009), Haddeland et al. (2011), Ghosh and Katkar (2012), Giorgi and Coppola (2012)and Hagemann et al. (2013) reported that the GCMs are generally taken resort to. These climate models are coupled with the Hydrological Models and help simulating input of the regional weather parameters being translated into the changes in the hydrological processes.

3.1 Integration of GCMs, RCMs and hydrology model and multi model ensemble approach

Knutti (2010)reported that there had been quite a few successful GCM and RCM based studies regarding seasonal forecasts, crop yield, seasonal climatic.Lee and Wang (2012), Palmer et al. (2005) and Tomassetti et al. (2005)too have studied atmospheric circulation predictability using climate models.These studies have reviewed the application of Multi-model Ensembles till 2004. The application of multiple models supports the retrieval of superior predictions than those from a single model. Surprisingly, it has been found that even the output addition of a poor model can improve a prediction as the individual models are prone to produce overconfident-output (Knutti, 2010). Apparently it seems obvious that only the use of the good aspects of all models will be beneficial. Actually, inclusion of those models that provide not so desirable output in multiple predictions would give robust information about uncertainty in the prediction. The performance of the Multi-Model Ensembles (MMEs) is dependent on the skill and the level of overconfidence of the participating individual models. It thus envisages that multi-model ensembles can indeed locally outperform a 'best-model' approach, provided the single-model ensembles are overconfident Knutti(2010) andWeigel (2008).

The recent advancement in the hydrological studies which are taking into account the impact of the changing climate is that of the use of Multi-Model Ensembles (MMEs). The MMEs are considered capable of yielding much reliable outcomes. The scientist community that is in favour of the use of MMEs proclaims that the concept behind

MMEs is the simple statistical normalization of n number of samples. Thus higher is the n the lesser the possibility of deviation of each model outcome from the mean.

Kabat (2013) stressed on the urgent need for attention to be paid towards the multi-model ensemble approach to future water resource scenarios.Table 1 (inspired by the work of Teutschbein and Seibert, 2010) enlists some of the recent work hydrological studies conducted using MMEs.

Table 1: Brief overview of some of the Hydrological Studies using Multi-Model Ensembles

S No.	Reference	Study site	GHG emission scenarios	Resolution (Km x Km)	Hydrological models
1.	Hagemann et al. 2013	Global study of major catchments	3control A2 B1	50x 50	8 MPI-HM, LPJmL, WaterGAP, VIC,Mac-PDM.09, H08,GWAVAand JULES
2.	SpernaWeiland et al. 2012	Global runoff study	2 control A1B	50x 50	PCR-GLOBWB
3.	Gosling et al. 2010	Global runoff study of 65000 catchments	4 control A1B, A2&B2	50x 50	Mac-PDM.09
4.	Block et al. 2009	19,100 km2 Brazil: Iguatu River (Jagua-ribeRiver basin)	1 control	Not specified	ABCD, SMAP
5.	Leander et al. 2008	21,000 km2France, BeNeLux,Germany: MeuseRiver	2control A2	50 x 50	1 HBV
6.	Moore et al.2008	287–3808 km2Sweden:Arbogaa° n, Hedstro¨ mmen,Ko¨ pingsa°n andKollba¨ csa°n River	3control A2,B2	Not specified	GWLF
7.	Bu¨rger et al. 2007	Size not specifiedSpain: Upper Gallego-catchment(Ebro)	2control A2	50 x 50	2learning machines: SVM, RVM
9.	De Wit et al.2007	33,000 km2 France, BeNeLux, Germany: MeuseRiver	2control A2	50 x 50	1 HBV
10.	Graham et al. 2007	185,000–1.6 million km2Europe: BothnianBay, Baltic and Rhine Basin	3control A2,B2	50 x 50	2 HBV, WASIM
11.	Horton et al. 2006	39–185 km2Switzerland: 11mountainCatchments	3control A2,B2	50 x 50	1 GSM-SOCONT

12.	Booij 2005	21,000 km2France,BeNeLux, Germany:Meuse River	2 control Double CO2 concentration	20 x 20	1(3)HBV (3differentresolutions)
13.	Leung et al.2004	668,000 km2USA: Columbiaand Sacramento-San Joaquin River	3controlCO2 at 1995levelsbusiness as usual	40 x 40 50 x 50	Direct use

In the opinion of Palmer et al. (2005) the only drawback the projections drawn with the help of MMEs is that they, with their present efficiency level, are unable to represent the uncertainties comprehensively in the model-outputs even after being superior to single-model ensembles. Fulfilling many a condition like regional, seasonal, choice and type of prediction and etc. makes a model *best* or *not so best*. ButWeigel et al. (2008) and Knutti (2010) stressed on the point that the day Single Model Ensembles (SMEs) could be developed properly; their prediction-skill would stand as unbeatable.

The simulation of the regional and national level impact of climate change upon the hydrology is essential for policymaking to enable societies and economies avert or adapt to the impending deterioration of the fresh water resources (www. climatewizardcustom.org/docs/Climate_Models). India has recently launched two national programmes i.e. National Action Plan on Climate Change (NAPCC, 2008) and National Water Mission (NWM, 2010) which are in line with the international commitments on mitigation and adaptation and aimed to ensure equitable distribution of water resources through integrated water resource management.

4. Discussion

Thus as far as the above facts are concerned this field of model based hydrological studies is still in its infancy. Some necessary groundwork has yet to be done before the climate models judged for reliability of their outcomes to carry out the hydrological research. According to Lemos et al.(2012) there is a need for collaborative effort to fill up the gap between the understanding of the scientific community of any climate information being *useful* and that of the recognition of such an information as *usable* by the decision-makers/ policymakers. After this only must the GCMs and the RCMs be subjected to use or to tests to assess their efficiency in studying the interface between Climate change &the eventual (if any) hydrological disruptions.Coming to the question of refining the science of Simulation-Modelling we see that at present day thrust is upon the use of MMEs. Knutti (2010) also brings into limelight the fact that while models are clearly getting more comprehensive, it is yet unclear how much of their convergence with observations is due to better understanding of the processes or due to increased realism in parameterisation. Heeven emphasised on the need for allowing extreme models to be also the part of theensembles rather than choosing yet another average performing model.Also that the major loop holes in the models may help understanding the model-functions or even model-malfunctions. On the other hand, Gosling (2013) points out towards the major challenge of improving the model performance in terms of the quantification of the uncertainties in the use of model outcomes.So when both the above mentioned authors' views are put together we find ourselves at the doorstep of a challenge ofimproving models' quantification capacities might that might see a way out through Knutti's suggestion of taking chances with the extreme models.

It becomes clear from the Table 1 that there hasn't been any MME based studies for the river basins of India. Different permutation and combinations of simulation models have yet to be tried for the Indian River basin. And then can we really effectively strategise their management to combat the water crisis in the changing climate.

The interfaces and the interconnectivities of monsoonal climate with the occurrences of extreme weather events, temporal and spatial variation in rainfall, shared river systems, predominance of agriculture, increase in human population demands a continued collaboration among different stakeholders / states / disciplineswith respect to water security and climate change. Furthermore, there is an urgent need of integrated research by civil engineers, hydrologists, water planner's/managers and academicians which would yield a wholesome solution.The measures taken by the Government of India in the form of NAPCC with other different missions to counter the impacts of climate change cannot be effectiveuntil and unless implemented with a determined capacity and that too inproper directions.

5. Conclusion

To conclude from the discussion above, it is clear that the climate-projections are yet not reliable for hydrological studies. Presently as we are moving towards more refined RCM approach with introduction of IPCC's Vth Report newer emission scenarios i.e. the RCPs (Representative Concentration Pathways) there is still scope of exploring and experimenting models to produce more reliable climate projections for hydrological use.
The state-of-the-art of fresh water resources, at global as well as national level, is a great matter of concern. Such a scenario of the world being trapped in the water-crisis beckons both the producers and users of model-generated projections, to promote the simulation-modelling as the torch bearer in the field of sustainable water management. MMEs have given the scientist the arena to cross check the basin level hydrological projections with that of the single model projections. But as far as the research in this field in India is concerned MMEs are yet to be applied to study major river basins of India for their runoff yield in the changing climate scenario.

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References

Alexander, L., Allen, S.,Bindoff, N.L., Bréon, F.M., Church, J., Cubasch,U., Emori, S., Forster,P.,Friedlingstein, P., Gillett,N., Gregory, J., Hartmann, D., Jansen, E.,Kirtman, B., Knutti, R., Krishna, K.K., Lemke, P.,Marotzke, J., Masson-Delmotte, V.,Meehl, G., Mokhov, I.,Piao, S.,Plattner, G.K.,Dahe, Q., Ramaswamy, V., Randall, D., Rhein, M., Rojas, M., Sabine, C.,Shindell, D., Stocker,T.F., Talley, L., Vaughan, D. andXie, S.P., 2013. Summary for Policy Makers: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Arora, V.K., Boer, G.J., 2001. Effects of simulated climate change on the hydrology of major river basins. Journal of Geophysical Research 106, 3335–3348.

Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutik, J.P., 2008. Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change.33–48.

Beyene, T., Lettenmaier, D.P., Kabat, P., 2009. Hydrologic impacts of climate change on the Nile River Basin: implications of the 2007 IPCC scenarios. Climatic Change 100, 433–461.

Block, P.J.,Filho, F.A.S., Sun, L., Kwon, H.H., 2009. A Stream-flow Forecasting Framework using Multiple Climate and Hydrological Models. Journal of American Water Resources Association 45, 828–843.

Booij, M.J., 2005. Impact of climate change on river flooding assessed with different spatial model resolutions.

Bormann, H., 2010. Runoff Regime Changes in German Rivers Due to Climate Change. Erdkunde 64, 257–279.

Bu¨ rger, C.M., Kolditz, O., Fowler, H.J., Blenkinsop, S., 2007. Future climate scenarios and rainfall-runoff modelling in the Upper Gallego catchment (Spain). Environmental Pollution 148, 842–854.

Chakrapani, G.J., 2005. Factors controlling variations in river sediment loads. 88, 569–575.

Costard, F., Gautier, E., Brunstein, D., Hammadi, J., Fedorov, A.,Yang, D., Dupeyrat, L., 2007. Impact of the global warming on the fluvial thermal erosion over the Lena River in Central Siberia. Geophysical Research Letters 34, 1–4.

Davidson, E.A., de A Alessandro, C., Artaxo, P., Balch,J.K., Brown, I.F., Bustamante, M.M.C.,Coe,M.T., DeFries, R.S., Keller, M.,Longo, M., Munger,J.W., Schroeder, W.,Soares-Filho,B.S., Souza Jr., C.M.,&Wofsy, S.C., 2012. The Amazon basin in transition. Nature 481, 321–328.

De Wit, M. J. M., et al. 2007. Impact of climate change on low-flows in the river Meuse. Climatic Change 82, 351–372.

Fowler, H.J., Archer, D.R., 2005. Hydro-climatological variability in the Upper Indus Basin and implications for water resources, Proceedings of symposium S6 on Regional Hydrological Impacts of Climatic Change—Impact Assessment and Decision Making: Seventh IAHS Scientific Assembly.Foz do Iguaçu, Brazil, IAHS Publ. 295, 131–138

Gain, A.K., Immerzeel, W.W., Sperna-Weiland, F.C., Bierkens, M.F.P., 2011. Impact of climate change on the stream flow of lower Brahmaputra: trends in high and low flows based on discharge- weighted ensemble modelling. Hydrology and Earth System Sciences Discussions 8, 365–390.

Gerten, D.,Gomes, S.,Gosling, S.N.,Hagemann, S., Hanasaki, N., Harding, R., Heinke, J., Kabat, P., Koirala, S., Oki, T., Polcher, J., Stacke, T., Viterbo, P., Weedon, G.P. and Yeh, P., 2011. Multi-model Estimate of the Global Terrestrial Water Balance: Setup and First Results. Journal of Hydrometeoroloy 12, 869–884.

Ghosh, S., Dutta, S., 2012. Impact of climate change on flood characteristics in Brahmaputra basin using a macro-scale distributed hydrological model. Journal of Earth System Science 121, 637–657.

Ghosh, S., Katkar, S., 2012.Modeling Uncertainty Resulting from Multiple Downscaling Methods in Assessing Hydrological Impacts of Climate Change. Water Resources Management 26, 3559–3579.

Ghosh, S., Misra, C., 2010. Assessing Hydrological Impacts of Climate Change.Modeling Techniques and Challenges. The Open Hydrology Journal 4, 115–121.

Giorgi, F.,Coppola, E., Solmon, F., Mariotti, L., Sylla, M.B., Bi, X., Elguindi, N., Diro, G.T., Nair, V., Giuliani,G., Turuncoglu, U.U., Cozzini, S., Güttler, I., O'Brien, T.A., Tawfik, A.B., Shalaby, A., Zakey, A.S., Steiner, A.L., Stordal, F., Sloan, L.C., Brankovic, C.,2012 RegCM4: model description and preliminary tests over multiple CORDEX domains. Climate Research 52, 7–29.

Gosain, A.K., Rao, S., Arora, A., 2011. Climate change impact assessment of water resources of India. Current Science 101, 356–371.

Gosling, S.N., 2013. Systematic quantification of climate change impacts modelling uncertainty,Impacts World 2013, International Conference on Climate Change Effects, Potsdam, 1–7.

Gosling, S.N., Bretherton, D., Haines, K., Arnell, N.W., 2010. Global hydrology modelling and uncertainty: running multiple ensembles with a campus grid Global hydrology modelling and uncertainty. Philosophical Transactions of the Royal Society 368, 4005–4021.

Graham, L.P., Hagemann, S., Jaun, S., Beniston, M., 2007. On interpreting hydrological change from regional climate models. Climatic Change 81, 97–122.

Haddeland, I.,Clark, D.B., Franssen, W., Ludwig, F., Voß, F.,Arnell, N.W., Bertrand, N.,Best, M., Folwell, S.,

Hagemann, S., Chen, C., Clark, D.B., Folwell, S., Gosling, S.N., Haddeland, I., Hanasaki, N., Heinke, J., Ludwig, F., Voss, F., Wiltshire, A.J., 2013. Climate change impact on available water resources obtained using multiple global climate and hydrology models. Earth System Dynamics 4, 129–144.

Horton, P., Schaefli, B., Mezghani, A., Hingray, B., and Musy, A.,2006. Assessment of climate-change impacts on alpine discharge regimes with climate model uncertainty. Hydrological Processes 20, 2091–2109.

Jain, S.K., Kumar, V., 2012. Trend analysis of rainfall and temperature data for India. Current Science 102, 37–49.

Jain, S.K., 2011. Population rise and growing water scarcity in India – revised estimatesand required initiatives. Current Science. 101, 271-276.

Jha, M., Arnold, J.G., Gassman, P.W., Giorgi, F., Gu, R.R., 2007. Climate Change Senstivity Assessment on Upper Mississippi River Basin Streamflows Using SWAT. Journal of the American Water Resources Association 3232, 997–1015.

Jones, J.A., 2011. Hydrologic responses to climate change: considering geographic context and alternative hypotheses. Hydrological Processes 1–5.

Kabat, P., 2013. Water at a Crossroads. Nature Climate Change 3, 11-12.

Knutti, R. 2010. The end of model democracy? An editorial comment. Climate Change 102, 395–404.

Leander, R., Buishand, T.A., van den Hurk, B.J.J.M., de Wit, M.J.M., 2008. Estimated changes in flood quantiles of the river Meuse from resampling of regional climate model output. Journal of Hydrology 351, 331–343.

Lee, J., Wang, B., 2012. Seasonal Climate Prediction and Predictability of Atmospheric Circulation, in "Climate Model".In:Druyan, L. (Ed.). In Tech Press, Crotia, pp.19–42.

Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the Climate Information Usability Gap. Nature Climate Change 2, 789-793.

Mall, R.K., 2013. Climate Change and Water Security: An Indian Perspective, Signatures, Newsletter of the ISRS–AC 25, 119- 133.

Mall, R.K., Bhatla R., Pandey S.N., 2007: "Water resources in India and impact of climate change", JalvigyanSameeksha (Min of Water Resources) 22, 157-176.

Mall, R.K., Gupta, A., Singh, R., Singh, R.S., Rathore, L.S., 2006. Water resources and climate change: An Indian perspective. Current Science 90, 1610–1626.

Mauser, W., Bach, H., 2009. PROMET – Large scale distributed hydrological modelling to study the impact of climate change on the water flows of mountain watersheds. Journal of Hydrology 376, 362–377.

Moore, K., Pierson, D., Pettersson, K.,Schneiderman, E.,Samuelsson, P.,2008. Effects of warmer world scenarios on hydrologic inputs to Lake Ma¨lraen, Sweden and implications for nutrient loads. Hydrobiologia 599, pp. 191–199.

National Action Plan on Climate Change (NAPCC), 2008 (http:/pmindia.nic.in/Climate%20Change_16.03.09.pdf).

National Water Mission under National Action Plan on Climate Change, Government of India, Ministry of Water Resources, India, 2010.

Nijssen, B., O'Donnell, G.M., Hamlet, A.F., Lettenmaier, D.P., 2001. Hydrologic Sensitivity of Global Rivers to Climate Change. Climatic Change 50, 143–175.

Palmer, T.N., Shutts, G.J., Hagedorn, R., Doblas-Reyes, F.J., Jung, T., Leutbecher, M., 2005. Representing Model Uncertainty in Weather and Climate Prediction. Annual Reviews on Earth and Planetary Sciences 33, 163–193.

Randall, D.A., Wood, R.A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., Taylor, K.E., 2007. Climate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

Soliman, E.S.A., Sayed, M.A.A.,Jeuland, M., 2009. Impact Assessment of Future Climate Change for the Blue Nile Basin, Using a RCM Nested in a GCM. Nile Basin Water Engineering Scientific Magazine 2, 15–30.

Taye, M.T., Ntegeka, V., Ogiramoi, N.P., 2010. Assessment of climate change impact on hydrological extremes in two source regions of the Nile River Basin. Hydrology and Earth System Sciences Discussions 7, 5441–5465

Teutschbein, C., Seibert, J., 2010. Regional Climate Models for Hydrological Impact Studies at the Catchment Scale: A Review of Recent Modelling Strategies. Geography Compass 7, 834–860.

Tomassetti, B., Coppola, E., Verdecchia, M., Visconti, G., 2005. Advances in Geosciences Coupling a distributed grid based hydrological model and MM5 meteorological model for flooding alert mapping. Advances in Geosciences 2, 59–63.

Wang, Y.,Leung, L.R., McGregor,J.L., Lee, D.K., Wang, W.C., Ding, Y., Kimura, F., 2004. Regional Climate Modeling: Progress, Challenges, and Prospects. Journal of Meteorological Society of Japan 82, 1599–1628.

Weigel, A.P., Liniger, M.A., Appenzeller, C., 2008. Can multi-model combination really enhance the prediction skill of probabilistic ensemble forecasts? Quaterly Journal of The Royal Meteorological Society 134, 241–260.

Weiland, F.C.S., van Beek, L.P.H., Weerts, A.H., Bierkens, M.F.P., 2012. Extracting information from an ensemble of GCMs to reliably assess future global runoff change. Journal of Hydrology 412-413, 66–75.

Wetherald, R.T., Manabe, S., 2002. Simulation of hydrologic changes associated with global warming. Journal of Geophysical Research 107, ACL 1–7.

www. climatewizardcustom.org/docs/Climate_Models accessed on 19.06.2014

Yang, D.,Kane, D.L., Hinzman, L.D., Zhang, X., Ye, H., 2002. Siberian Lena River hydrologic regime and recent change. 107, 1–10.

Ye, B., Yang, D., Zhang, Z., Kane, D.L., 2009. Variation of hydrological regime with permafrost coverage over Lena Basin in Siberia. Journal of Geophysical Research 114, 1–12.