

**CLIMAT CHANGE IMPACT ASSESSMENT ON WATER RESOURCES
OF KARKHEH BASIN AND FORMOULATION
OF ADAPTATION STRATEGIES**

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OF ADAPTATION STRATEGIES**

by

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Submitted

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CERTIFICATE

This is to certify that the thesis entitled, “**CLIMATE CHANGE IMPACT ASSESSMENT ON WATER RESOURCES OF KARKHEH BASIN AND FORMULATION OF ADAPTATION STRATEGIES**,” being submitted by Mr. **Hamidreza Solaymani Osbooei** to the Indian Institute of Technology Delhi for the award of Doctor of Philosophy is a record of bonafide research work carried out by him under my guidance and supervision in conformity with the rules and regulations of the Indian Institute of Technology Delhi. The research report and results presented in this thesis have not been submitted, in part or full, to any other university or Institute for the award of any degree or diploma.

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ABSTRACT

Climate, freshwater, ecological and socio-economic systems are inter-connected in complex ways, so a change in any one of these systems in turn triggers impacts in other systems. The major challenges concerning fresh water include: experiencing extremes of too much and/or, too little water, and consequent water issues. Each of these problems may be intensified by climate change in semi-arid areas. Existing research and observational evidences provides strong arguments that future climate may change significantly and, therefore, impact the water resources of the given basin. Thus, the strategies that can be used to mitigate possible negative impacts of climate change on water resources are of great importance. During the past decades, a great deal of research has been devoted to the detection of climate change impact on hydro-climatic components. The intensity and character of the impact, however, can vary significantly from region to region.

This thesis intends to investigate the impacts and adaptation strategies to climate change on water resources, and shall also compare adaptation strategies to cope with climate change impacts using an Integrated Water Resource Management (IWRM) approach for a pilot area in Iran, i.e., the Karkheh River Basin (KRB). Understanding the hydrologic response to climate change for watersheds of this type is particularly important due to the dependence of major water systems on the contribution made by the stream-flow.

Two available Regional Climate Models (RCMs) under A2, B2, and A1B emission scenarios were used for the climate change impacts assessment on water resources in the study area. The SWAT model was then used to evaluate the sensitivity of annual and seasonal stream-flows from the KRB to possible changes in climate. The change in precipitation had the most significant impact on the magnitude of annual water yield (WYLD). Temperature rise as well as precipitation reduction shall cause a significant reduction in total stream-flow. The outcomes of the projected model have shown that the maximum increase in the WYLD is 8.2 mm under A2 scenario in August whereas the maximum reduction is 78.3 mm under B2scenario in January in the Upper KRB. Similar trends were also predicted for the Middle and Lower KRB. The pattern of the monthly change in evapotranspiration (ET), WYLD and discharge is largely governed by the combined impact of temperature and precipitation in a very complex manner. Changes were also calculated using the differences between the averages of the future time period (2070–2099) with respect to the average of the baseline time period (1970–1999). While the A1Bscenarioshowsa general reduction in the WYLD and ET across most of the KRB, however, there are variations over the Middle and Lower KRB. For example, a large increase in the WYLD has been projected in the Lower KRB during the autumn months of OND. Moreover, there are also uncertainties in climate change projections which in turn result in uncertainty in both climate and hydrologic projections. The analysis also revealed that the middle KRB is the most stable sub-region within the KRB in response to future climate change impacts mainly due to the prevailing irrigated cultivation. The risk of drought and heat stress is thought to increase

in whole of the study area. Overall, the present study shows the consequences of climate change on the water resources of the KRB and shall be useful in formulating the adaptation options in a sustainable manner.

The final part of this research work focused on formulating adaptation measures as well as research into adaptation strategies to climate change in the study area using the IWRM and prioritization of the same. Enhancing the water use efficiency is the simplest answer to cope with water scarcity. In order to formulate the adaptation scenario, various possible adaptation operations have been recognised first and then the validated application operations have been ranked based on questionnaire response and expert judgment approach. It is required to prioritize the validated adaptation operations, with respect to functionalities/capabilities for hydrological modelling, social-economical, and ecological/technological limitations which were achieved using the Strengths, Weaknesses, Opportunities and Threats analysis (SWOT), and Partial Order Analysis (POA). Thus, four adaptation activities have been suggested, two of these being agricultural and land management system activities (Ac.1 and Ac.2), another one being land-use change activity (Ac.3), and the fourth one being cropping pattern change (Ac.4).

The SWAT model allows for simulation of management practices and therefore it is best used for exploring the impact of adopting a specific adaptation option. In the present study SWAT has been used to assess the impacts of adopting specific cultivation field operations as well as changes in land-use of range and forest lands. The impact of

suggested adaptation activities had various effects on hydrology and the same has been depicted through tracking major hydrological components; e.g. surface runoff, groundwater and sediment erosion. Amongst the suggested adaptation scenarios, activities Ac.1 and Ac.2; that include terracing, strip cropping, Grade Stabilization Structure (GSS), and contouring were found to influence significantly the desired hydrologic components. Both Ac.1 and Ac.2 were also found to sustain crop production against the extreme hydrologic conditions. The effect of Ac.3 is comparatively low on influencing the local hydrology. Moreover, converting rain-fed cultivated land to range and forest lands will result in the loss of income to the farming community.

Agriculture in the KRB if fully integrated with the economic activity of the region by associating with more efficient agriculture activities such as use of new technology to irrigate, using more efficient cultivars, and using proper fertilizers can enhance the yield and compensate for loss of economic income. However, such increase in efficiency is associated with enhanced use of fertilizer. Therefore, reduction in nutrient loading in the watershed needs to be addressed in conjunction. Ac.4 (using the Syrian 4, cultivar of durum wheat) has also resulted in some savings in water. The land-use and cropping pattern changes were successful in bringing about the desired changes to the hydrologic components.

सार

जलवायु, ताजा पानी, पारिस्थितिक और सामाजिक-आर्थिक प्रणाली जटिल तरीके से आपस में जुड़े हुए हैं, इसलिए इन प्रणालियों में किसी भी एक के परिवर्तन से अन्य प्रणालियों में होने वाले प्रभावों को सक्रिय किया जा सकता है। ताजा पानी से संबंधित प्रमुख चुनौतियों में शामिल हैं: बहुत ज्यादा और / या बहुत कम के चरम का सामना करना पड़ रहा है, पानी, और परिणामस्वरूप पानी के मुद्दों, इन समस्याओं में से प्रत्येकअर्द्ध शुष्क क्षेत्रों में जलवायु परिवर्तन से तेज किया जा सकता है। मौजूदा शोध और पर्यवेक्षण प्रमाण मजबूत तर्क प्रदान करता है, जो भविष्य में जलवायु को काफी बदल सकते हैं और इसलिए, करखेहवेसिन के जल संसाधनों को प्रभावित करसकतेहैं। इस प्रकार, विभिन्नरणनीतियों का उपयोग जलवायु के संभावित नकारात्मक प्रभावों को कम करने के लिए किया जा सकता है। पिछले दशकों के दौरानशोध, जलवायु परिवर्तन का हाइड्रो-क्लाइमेट पर प्रभाव पता लगाने के लिए समर्पित है। प्रभाव की तीव्रता और चरित्र, प्रत्येक क्षेत्र में काफी भिन्न हो सकते हैं।

इस शोध काउद्देश्यपानी पर जलवायु परिवर्तन के प्रभावों और अनुकूलन रणनीति की जांच करने का है। संसाधनों, अनुकूलन रणनीति की तुलना का उपयोग कर जलवायु परिवर्तन के प्रभावों से निपटने के लिए ईरान में एक पायलट क्षेत्र करखेह नदी बेसिन (केआरबी) के लिए एक एकीकृत जल संसाधन प्रबंधन (आईडब्ल्यूआरएम) दृष्टिकोणप्रस्तुतकरनाभीहै। जलवायु परिवर्तन के लिए धारा प्रवाह द्वारा किए गए योगदानपर जलविज्ञानी प्रतिक्रिया को समझना, प्रमुख प्रकार की जल प्रणालियों की निर्भरता के कारण इस प्रकार के वाटरशेड विशेष रूप से महत्वपूर्ण हैं।

अध्ययन क्षेत्र में जल संसाधनों पर जलवायु परिवर्तन प्रभावों के मूल्यांकन के लिए उपलब्धजलवायु मॉडल (आरसीएम) ए 2, बी 2, और ए 1 बी का उपयोग किया है। स्वातंत्र्य मॉडल को केआरबी से वार्षिक और मौसमी स्ट्रीम-प्रवाह की संवेदनशीलता का मूल्यांकन करने के लिए उपयोग किया जाता था। जलवायु में संभावित बदलावों के लिए वर्षा में होने वाले परिवर्तन में सबसे महत्वपूर्ण प्रभाव पड़ा। वार्षिक जल उपज (वाईएलएडीडी) की मात्रा तापमान वृद्धि और साथ ही वर्षा में कमी होगी तथाकुल प्रवाह प्रवाह में एक महत्वपूर्ण कमी का कारण अनुमानित मॉडल के परिणामों में दिखाया गया है कि अगस्त में ए 2 परिदृश्य में अधिकतम वृद्धि 8.2 एमएम है। जनवरी में बीएससीएनारियो के तहत अधिकतम कमी 78.3 मिमी है जो कि उच्च केआरबी में है। समान रुझान

भी मध्य और लोअर केआरबी के लिए भविष्यवाणी की गई थी और मासिक परिवर्तन का पैटर्नवाष्पशीलता (ईटी), वाइ.वाय.डी.डी. और निर्वहन मुख्य रूप से संयुक्त प्रभाव से नियंत्रित होता है। परिवर्तनों का उपयोग करके भी गणना की गई के संबंध में भविष्य की अवधि (2070-2099) के औसत के बीच अंतर बेसलाइन समय अवधि (1970-1999) का औसत जबकि ए 1 बीएससीनारीशोव्सा सामान्य कमी अधिकांश केआरबी में विश्व बैंक और ईटी में, हालांकि, मध्य में भिन्नताएं हैं औरलोअर केआरबी उदाहरण के लिए, WYLD में एक बड़ी वृद्धि के दौरान लोअर केआरबी में अनुमान लगाया गया है। शरद ऋतु के महीनों के अलावा, जलवायु परिवर्तन के अनुमानों में भी अनिश्चितताएं हैं जो जलवायु और हाइड्रोलोजी अनुमानों दोनों में अनिश्चितता का परिणाम है। विश्लेषण से पता चला कि भविष्य के जवाब में के.आर.बी. के बीच मध्यम केआरबी सबसे स्थिर उप-क्षेत्र है और प्रचलित सिंचाई की खेती के कारण मुख्य रूप से जलवायु परिवर्तन प्रभाव पड़ता है। सूखा का खतरा और गर्मी तनाव पूरे अध्ययन क्षेत्र में वृद्धि के बारे में कुल मिलाकर, वर्तमान अध्ययन से पता चलता है, केआरबी के जल संसाधनों पर जलवायु परिवर्तन के परिणाम और एक टिकाऊ ढंग से अनुकूलन विकल्प तैयार करना इसके लिए उपयोगी होंगे।

इस शोध कार्य का अंतिम भाग अनुकूलन उपायों के साथ-साथ अनुकूलन उपायों पर केंद्रित है। IWRM का उपयोग करके अध्ययन क्षेत्र में जलवायु परिवर्तन के अनुकूलन रणनीतियों में शोध करना और पानी के

उपयोग की दक्षता बढ़ाने, पानी की कमी से निपटने के लिए जरूरी उपाय प्रदान करना है। अनुकूलन परिदृश्य तैयार करने के लिए, विभिन्न संभव अनुकूलन आपरेशनों को पहले पहचाना गया है और फिर मान्य एप्लीकेशन का उपयोग किया गया है। प्रश्नावली प्रतिक्रिया और विशेषज्ञ निर्णय दृष्टिकोण पर आधारित रैंक प्राथमिकता के लिए आवश्यक है।

हाइड्रोलॉजिकल के लिए कार्यात्मकताओं / क्षमताओं के संबंध में मान्य अनुकूलन संचालन मॉडलिंग, सामाजिक-आर्थिक, और पारिस्थितिक / तकनीकी सीमाएं जो हासिल की गई थी ताकत, कमजोरियों, अवसरों और धमकी विश्लेषण (एसओडब्ल्यूटी) और आंशिक आर्डर का उपयोग करना विश्लेषण (पीओए) इस प्रकार, चार अनुकूलन गतिविधियों का सुझाव दिया गया है, जिनमें से हैं: कृषि और भूमि प्रबंधन प्रणाली की गतिविधियों (ए 1 और एसी 2), जमीन का इस्तेमाल परिवर्तन गतिविधि (एए 3), और चौथा एक फसल काटना पैटर्न (एसी 4)।

SWAT मॉडल प्रबंधन प्रथाओं के अनुकरण के लिए अनुमति देता है और इसलिए इसका सर्वोत्तम उपयोग किया जाता है। वर्तमान अध्ययन में एक विशिष्ट अनुकूलन विकल्प को अपनाने के प्रभाव की खोज करना स्वाट द्वारा किया गया है। विशिष्ट खेती क्षेत्र के संचालन को अपनाने के प्रभावों के साथ-साथ में परिवर्तनों के आकलन के लिए सीमा और वन भूमि का उपयोग प्रयोग किया जाता है। सुझाए गए अनुकूलन गतिविधियों के प्रभाव में कई भिन्नताएं थीं, हाइड्रोलॉजी पर प्रभाव और उसी प्रकार के प्रमुख जल विज्ञान ट्रेकिंग के माध्यम से दर्शाया गया है अवयव; जैसे सतह अपवाह, भूजल और तलछट का क्षरण। सुझाव के बीच में अनुकूलन परिदृश्य, गतिविधि ए 1 और ए.सी. 2; इसमें टेरेसिंग, स्ट्रिप फसलिंग, ग्रेड शामिल हैं। स्थिरीकरण संरचना (जीएसएस), और समोच्च का काफी वांछित प्रभाव पाया गया। हाइड्रोलॉजी घटकों एसी 1 और एसी 2, दोनों के मुकाबले फसल उत्पादन को बनाए रखने के लिए भी पाया गया है चरम हाइड्रोलॉजी स्थितियां स्थानीय पर प्रभाव डालने पर एसी 3 का प्रभाव अपेक्षाकृत कम है।

इसके अलावा, बारिश से खिलाया खेत वाले जमीन को रेंज और वन भूमि में परिवर्तित करने का परिणाम कृषि समुदाय के लिए आय का नुकसान होगा। केआरबी में कृषि अगर संबद्ध द्वारा पूरी तरह से क्षेत्र की आर्थिक गतिविधि अधिक कुशल कृषि गतिविधियों के साथ एकीकृत हो: जैसे कि सिंचाई के लिए नई तकनीक के उपयोग के साथ, और अधिक का उपयोग कर कुशल किसानों, और उचित उर्वरकों का उपयोग कर उपज को बढ़ा सकते हैं और आर्थिक आय नुकसान के लिए क्षतिपूर्ति कर सकते हैं। वाटरशेड में पोषक तत्वों की लोडिंग में कमी को संयोजन और संबोधित किया जाना चाहिए।

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List of Abbreviations and Symbols

ANN	Artificial Neural Network
AOGCM	Atmospheric- Oceanic General Circulation Model
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
APF	Adaptation Policy Framework
ARIMA	Auto-Regressive Integrated Moving Average
ARMA	Auto-Regressive Moving Average
ARS	Agricultural Research Service
AWD	Alternative Wetting and Drying
BMP	Best Management Practice
CDAT	Climate Data Analysis Tools
CGCM	Canadian Global Coupled Model
CH_EROD	Factor of channel erodibility
CH_S2	Main channel Slope
CN2	Curve Number for wetting condition II
CPWF	Challenge Program for Water and Food
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management
DEM	Digital Elevation Model
dsm ⁻¹	Deci- Siemens per meter
DDC	Data Distribution Centre
ECHAM5	Fifth generation of the global climate model developed by the Max
EPIC	Erosion-Productivity Impact Calculator
ERDAS	Earth Resources Data Analysis System

E _a	Evapotranspiration
ET	Evapotranspiration
ET _i	Evapotranspiration Index
FAO	Food and Agriculture Organisation
GCM	General Circulation Model
GLEAMS	Groundwater Loading Effects on Agricultural Management Systems
GIS	Geographical Information System
GSS	Graded Stabilization Structure
HadRM3	RM3 Series generated by Hadley Centre for Climate Prediction, UK
HEC-RAS	Hydrologic Engineering Centre-River Analysis System model
HI	Harvest Index
HRU	Hydrologic Response Unit
HU	Heat Unit
KRB	Karkheh River Basin
IMO	Iran Meteorological Organisation
IPCC	Intergovernmental Panel of Climate Change
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
LAI	Leaf Area Index
LH	Latin Hypercube
masl	meter above sea level
MEFIDIS	Modelo de Erosão Física e DIStribuído (Physically-based distributed
MoE	Ministry of Energy
NAOI	North Atlantic Oscillation Index

netCDF	Network Common Data Form
NSE	Nash-Sutcliffe Efficiency
OAT	One-factor-At-a-Time
OECD	Organisation for Economic Co-operation and Development
OV_N	Manning Coefficient for Overland
PBIAS	Percent of Bias
PET	Potential Evapotranspiration
PHU_PLT	Total Number of Heat Units for each Plant
POA	Partial Order Analysis
PP	Post Processing
ppmv	part per million by volume
PRECIS	Providing REgional Climates for Impacts Studies
Q_{gw}	Amount of the return flow
Q_{surf}	Surface Runoff
RCM	Regional Climate Model
RCPs	Representative Concentration Pathways
RegCM	Regional Climate Model originally developed at the National Centre
REMO	Regional Model developed by the Max Planck Institute for
R_{day}	Precipitation
ROTO	Routing Outputs to Outlet
RSR	Standard Deviation Ratio
SCS	United States Soil Conservation Service
SOM	Self Organizing Map
SRES	Special Report on Emission Scenarios

SRI	System of Rice Intensification
SRTM	Shuttle Radar Topography Mission
Sufi-2	Sequential Uncertainty Fitting Program
SW_0	Initial soil water content (mm of water)
SW_t	Final soil water content (mm of water)
SWAT	Soil and Water Assessment Tool
SWIM	Soil and Water Integrated Model
SWMM	Storm Water Management Model
SWOT	a structured planning method used to evaluate
SWRI	Soil and Water Research Institute
SWRRB	Simulator for Water Resources in Rural Basins
UNFCCC	United Nations Framework Convention on Climate Change
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USLE_C	Cropping factor of Universal Soil Loss Equation
USLE_P	Practice factor of Universal Soil Loss Equation
TAR	Third Assessment Report
V	Volume of water in the impoundment at the end of the day
V_{evap}	Volume of water removed from the water body by evaporation during
V_{flowin}	Volume of water entering the water body during the day
V_{flowout}	Volume of water flowing out of the water body during the day
V_{pcp}	Volume of precipitation falling on the water body during the day
V_{seep}	Volume of water lost from the water body by seepage
V_{stored}	Volume of water stored in the water body at the beginning of the day

WaSiM	Water Simulation Model
W_{seep}	Water entering vadose zone from soil profile (mm of water)
WG1	Working group one