The Anthropocene: Politik—Economics—Society—Science

Tsugihiro Watanabe
Selim Kapur · Mehmet Aydın
Rıza Kanber · Erhan Akça
Editors

Climate Change Impacts on Basin Agro-ecosystems

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Editors
Tsugihiro Watanabe
Graduate School of Global Environmental Studies
Kyoto University
Kyoto, Japan

Selim Kapur
Department of Soil Science and Plant Nutrition, Faculty of Agriculture
Çukurova University
Adana, Turkey

Mehmet Aydın
Department of Soil Science, Faculty of Agriculture
Mustafa Kemal University
Antakya, Turkey

Rıza Kanber
Department of Agricultural Structures and Irrigation Engineering
Çukurova University
Adana, Turkey

Erhan Akça
School of Technical Sciences
Adıyaman University
Adıyaman, Turkey

The cover photograph was provided by Adana Museum and shows Teşup or Tarhunda, the god of atmospheric events of rain, thunder and storm during the late Hittite Period (BC 700). This statue of Tarhunda (limestone) on a basalt oxen-driven chariot (2700 BP) was discovered by the Adana Regional Museum in the Lower Seyhan Irrigation Plain (the ICCAP site) in the late 1990s. To illustrate the drought theme, the photograph on the internal title page (iii) shows an abandoned well on the Seyhan Plain. Both photographs are used with the kind permission of the photographers.

For more information on this book, see: http://afes-press-books.de/html/APESS_18.htm.

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Foreword by Fujio Kimura

I was involved in the Impact of Climate Change on Agricultural Production System in Arid Area (ICCAP) Project, with its outcomes reported in this book, from its very beginning. My career as a meteorologist and climatologist was influenced by this project where I learned a lot on assessing the basin-wide impact of climate change on hydrological systems and agricultural production. During the collaboration with the leader, Dr. Watanabe, and the other researchers of the ICCAP, I tried to develop the future climate projection model for the target region. While this was quite a tough task for me, as I had mainly worked on the climate change in Japan, I remember being very happy when I finally achieved satisfactory results. We had lively discussions with many researchers and practitioners of different fields from Japan and abroad about the latest scientific issues and developments in methodology.

In the project, from the beginning, the collaborators in the fields of hydrology and agronomy had requested the establishment of a reliable climate change scenario with considerably higher horizontal resolution. Long discussions and exchanges of knowledge went on until a deep mutual understanding of "projection" and "prediction" was reached. I had primarily tried to convince them on the basis of the climate model and also how to use its outputs, and finally share the common comprehension concerning the mechanism of climate change and its prediction as well as the limitations on the prediction.

Climate change prediction with higher resolution and accuracy was the general requirement in the studies related to the ICCAP. During the ICCAP Project, across the world, higher-resolution general circulation models (GCMs) were being developed, and methods to downscale the GCM outputs were also being developed with improved regional climate models (RCM) nesting the GCM.

The future regional climate scenarios were generated when the ICCAP introduced the pseudo-global warming experiment, with the future climate change predictions by the GCM, the detailed climate distributions currently observed, and the RCM downscaling the GCM outputs. At the time, this method was the most advanced, offering higher accuracy and resolution. This technique is being still used in other countries, such as the USA.

The researchers in various fields, who had developed well-coordinated models to assess climate change utilising the generated regional climate scenarios, really seemed to feel that they provided exact and meaningful future predictions. In addition, with the sophisticated prediction of changes resulting from agricultural production and land and water use, an understanding of the necessary feedback of changes in agriculture and water use to the climate system was extended and resulted in new developments. While I regret that I myself did not record the development of the method related to the generation of the climate scenario in this book, it is my great pleasure that some of the chapters describe the method and use their outcomes, and refer to the journal paper that summarises the research results.

As mentioned above, related to the main target of the ICCAP, close collaborations and cooperation between the researchers of various academic fields were achieved with regard to climate change. The “warm and close cooperation” coordinated by the leader, Dr. Watanabe, seems to underpin each chapter in this book and appears explicitly at the surface of some chapters.

After the ICCAP Project, I have been involved in implementing research programmes on the development of the adaptation measures to climate change impacts on Japan, where my experiences and learning during the international ICCAP Project helped me solve domestic research issues and supported my research capability.

Such a cross-disciplinary and international “warm collaboration” as of the ICCAP is to be further enhanced. I hope the integrated approach to climate change impact assessment and the establishment of adaptation measures will be promoted extensively, leading to the basis for a sustainable society all over the world, where people are not subjected to the adverse effects of climate change.

Tokyo, Japan
March 2018

Dr. Fujio Kimura
Professor Emeritus of Tsukuba University
Programme Director, Advanced Atmosphere-Ocean-Land Modelling Program; Research Institute for Global Change
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Foreword by Eiichi Nakakita

As a researcher working in the relevant field, I am very pleased about the publication of this book on the integrated assessment of climate change impacts on hydrological processes and water resource management, including agricultural water use.

Needless to say, climate change due to global warming has become a major urgent issue for humanity. It is therefore vital to further accelerate assessment of its impacts, including the exact possible changes and problems, and establish adaptation measures based on the impacts that have already been observed. Under such circumstances, with the development of science and technology supported by the expansion of observation data and their availability, the accuracy and reliability of the projection of future climate change have certainly increased. On the other hand, integrating various aspects of impact assessment with adaptation scenarios is still developing, since it has many constraints, including its complex processes with diverse factors of relevant target fields, such as the natural physical and chemical phenomena, biosystems and ecosystems, as well as the lifestyle and production activities of the various societies.

In Japan, in view of this situation, the National Government Ministry of Education, Culture, Sports, Science, and Technology has been leading large-scale research programs, such as the Innovative Program of Climate Change Projection for the twenty-first century (KAKUSHIN) (2007–2012) and the Program for Risk Information on Climate Change (SOUSEI) (2012–2017), aiming at increased accuracy of projecting the future climate and precise impact assessment. The Integrated Research Program for Advancing Climate Models (TOUGOU) (2017–2022) was launched as their successor. In these programmes, I have been coordinating the team to more precisely forecast and assess the climate change impacts on hydrological systems, water resource management, and the eco-environmental system of basins. Drs. Kenji Tanaka, Tsugihiro Watanabe, Takanori Nagano, and Yoichi Fujiwara are the key researchers of the ICCAP Project whose methodologies and results are introduced in this book, and who have participated in the consecutive programmes mentioned above. This means that the outcomes of the ICCAP Project are partly reflected in the framework and methodologies of both the programmes of the internationally challenging research programmes. Additionally, the development and outcomes of these programs have served as a reference in the process of compiling this book in terms of academic sense with financial support. I am honoured that our programme has contributed to this publication.

In view of the urgency of the climate change issues, and considering the advancement history mentioned above, I have a strong interest in this publication. I believe that this book will be a major force in response to climate change, with the progress of application of its outcomes and further improvements.

Kyoto, Japan
March 2018

Dr. Eiichi Nakakita
Professor, Division of Atmospheric and Hydrospheric Disasters
Disaster Prevention Research Institute, Kyoto University
The Principal Investigator of the Research Theme D
"Integrated Hazard Projection" of the Integrated Research
Programme for Advancing Climate Models of MEXT
Ministry of Education, Culture, Sports
Science and Technology, Japan

Foreword by Cemal Saydam

Back in 2001, I was informed that a scientist from Japan named Tsugihiro Watanabe wished to visit me. I thought that he would be yet another scientist who was willing to establish a collaboration with us and as always I accepted with great pleasure. During a long conversation, we mutually agreed on a collaboration. However, it was initially difficult for me to assign a specific research grant group to further extend a possible cooperation. Having the quick approval of The Science and Technology Promotion Agency of Turkey's (TÜBİTAK) president, I was personally appointed to be in charge of the project since I realised that the proposed project encompassed the research interests of several grant committees.

It was challenging to set up everything, since we had to decide on a river basin in order to initiate this multidisciplinary project. Cross-boundary rivers certainly offer ideal basins to study, but in this part of the world, as can be seen today, it is hard—if not impossible—to plan scientific projects since there are so many other factors that scientists are not empowered to resolve. Considering all these factors and to eliminate obstacles that we were not in a position to handle, we mutually agreed on the Seyhan Basin as a case study area. Such a multidisciplinary project is not easy to coordinate and run smoothly in its rather complicated integrity, but we were lucky to have a gentleman named Prof. Dr. Rıza Kanber from the Çukurova University to fulfill this task. We are also deeply indebted to Prof. Dr. Mehmet Aydın for his valuable efforts in creating the initial link between Turkey and Japan for the ICCAP and selection of the Çukurova plain as the project site via discussions that started in Japan with Profs. Tsugihiro Watanabe and Tomohisa Yano, and followed in Turkey. Professors Aytekin Berkman, Osman Tekinel (deceased), and Neşet Kılınçer should be acknowledged for their invaluable efforts in developing the relationships with other universities, Government establishments, and TÜBİTAK. We also extend our thanks to Prof. Dr. Selim Kapur for his efforts regarding the decision given on the implementation site of the ICCAP.

Thus with the support of the Research Institute for Humanity and Nature (RIHN) and TÜBİTAK project, the study was set to roll out in 2002 and was finalised during 2007 with great success. This was one of the perfect examples of excellent scientific cooperation between different cultures and proved that such things can be achieved. It is nice to see that the termination of the project at the end of its expected lifetime was, in fact, the start of so many collaborations that are still running in a perfect manner. This book is the compilation of the outcomes and successes of the programme and a testament to the excellent collaboration.

Ankara, Turkey
March 2018

Dr. Cemal Saydam
Professor of Hacettepe University, Turkey
Former Vice-President of TÜBİTAK
The Scientific and Technological Research Council of Turkey

Preface

I am delighted that the latest research results from the integrated assessment of climate change impacts on basin hydrological systems and agricultural production have been collated for publication as a volume. As editor, I would like to express my sincere and profound gratitude to all contributors and those who have supported the research projects and publication of the findings.

The contents of this book consist of the outcomes of the large-scale research project Impact of Climate Change on Agricultural Production System in Arid Areas (ICCAP) of the Research Institute for Humanity and Nature (RIHN) in Kyoto, Japan. This ICCAP Project was implemented for five years, from April 2002 to March 2007. Its aim was to assess the impacts of global-warming-induced climate change on agriculture. The principal investigator of the project was Dr. Tsugihiro Watanabe. In the project, the Seyhan River Basin of the Mediterranean region of Turkey was selected as the main case study region. Scientists from various relevant academic disciplines, of Japan, Turkey, and other countries participated in the projects. At that time, it was a very ambitious project, which addressed the very urgent and complicated issues by introducing state-of-the-art technology and knowledge.

The RIHN, which launched and implemented the ICCAP Project, was founded by the Japanese Government's Ministry of Education, Culture, Sports, Science, and Technology (MEXT), with the aim of establishing new academic fields related to the global environment, with the recognition of "global environmental issues" as a major concern in the relationship between nature and human beings. This relationship is "culture" in its wider sense, and in this sense, the environmental problem is the cultural issue. The institute tried to promote exact cross-disciplinary approaches to the issues to identify their deep implication and propose practical solutions, beyond their collateral nature. In this policy and context, and as a matter of urgency, the project was carried out to assess climate change and its likely impact on agricultural production. The meaning and management of natural resources, including climate, in agricultural production were re-studied during the project, and the existing management knowledge was reviewed to re-tailor the wisdom for "*futurability*". Thus, the context of the ICCAP Project was a uniquely ambitious challenge rarely encountered in the studies of the other relevant research institutes.

The project initially targeted a different region of the Middle East. However, because of the security and social situation of the region as well as the appropriate research environment, the Seyhan River Basin of Turkey was selected as the main case study area. The project of the RIHN was implemented with the financial support of The Science and Technology Promotion Agency of Turkey (TÜBİTAK), with the participation of many Turkish researchers, principally from Çukurova University, and the engineers of the 6th Regional Directorate of the State Hydraulic Works (DSİ) in Adana, located in the centre of the case study. In this collaborative work, Dr. Rıza Kanber, Professor of Çukurova University, served as the leader of the Turkish Team.

Six sub-teams were established: climate, hydrology, vegetation, agriculture, irrigation, and economics based on the generated future climate change predicted to occur by the 2070s. This was the date each of the teams used when assessing future impacts on the basin hydrology and agriculture. Finally, possible and practical methods were developed and applied despite the difficulties encountered concerning the research approach and context of the project. These challenges and developments deserve to be highly appreciated.

The challenges and outcomes are summarised in the following chapters of this book. At the beginning, the basic ideas and techniques are introduced, and the outcomes of each sub-team are grouped in the following parts. In addition, because some years have passed since the completion of the project and further progress on the methodology has been made, the chapters have been updated and the relevant research outcomes of other researchers have been incorporated in the book. Although each chapter concerns an independent study so could theoretically be read in isolation, I respectfully suggest you pay attention to all the findings obtained from the mutual relationships and accumulated knowledge developed in multi-authored chapters.

Again, looking back on the ICCAP, while some years have passed, its perspectives and approaches still address ongoing challenges and remain at the forefront of research in the field of climate change impact assessment and adaptation strategy development. I hope this book will contribute to further development of strategies to address the issues, inspired by the methods and results summarised here, and applications corresponding to the exact case situation. In conclusion, I would like to express my gratitude for this publication, the fruitful outcomes of the project and the meticulous and dedicated input of my co-editors, Selim Kapur, Mehmet Aydın, Rıza Kanber, and Erhan Akça.

Kyoto, Japan
March 2018

Dr. Tsugihiro Watanabe
Guest Editor of *Climate Change Impacts on Basin Agro-ecosystems*
Professor, Graduate School of Global Environmental Studies, Kyoto University
The Principal Investigator of the ICCAP

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The guest editors would like to express their utmost gratitude to PD Dr. Hans Günter Brauch, an independent editor of five book series published by Springer Nature, for his everlasting support and the unlimited hours of work he devoted to enhancing the quality of this book. Dr. Vanessa Greatorex is highly acknowledged for helping to make each chapter understandable to learners of all levels by refining the English.

Contents

Chapter 1
An Integrated Approach to Climate Change Impact Assessment on Basin Hydrology and Agriculture

Tsugihiro Watanabe, Takanori Nagano, Rıza Kanber and Selim Kapur

Abstract Climate change, including changes in air temperature and precipitation, would affect the basin hydrological regime, and the change in the hydrological system might have some impacts on agriculture. To assess the impacts of climate change on the hydrology and agriculture of a basin, the relationship between climate and basin hydrology, and between hydrology and the agriculture of the basin need to be analysed systemically and integrally. In this study, an integrated approach to these analyses or diagnoses is developed for a better projection and evaluation of the climate change impacts as the foundation for better adaptation. It takes into account various complicated factors in these relationships, which are often uncertain and affect each other and must therefore be treated in a particular way.

Consequently, an integrated approach to the issues in question was developed and applied to a large-scale research project, which is the ICCAP Project of RIHN, Japan. The primary aim of the approach and the project was to integrate the concept and processes of the integration approach, which are outlined together with their application in the case study. The methodologies and major objectives of the integrated approach as the core task of the project were:

(1) To diagnose the structure of land and water management in agricultural production systems in a basin, and especially to evaluate quantitatively the relationship between cropping systems, the hydrological cycle, and water balance in farmland and its environs.
(2) To develop the methodology or model for integrated assessment of impacts of climate change and adaptations to it on agricultural production systems, mainly agricultural land and water management.

T. Watanabe, Professor, Kyoto University, Graduate School of Global Environmental Studies, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan; e-mail: nabe@kais.kyoto-u.ac.jp.

T. Nagano, Associate Professor, Kobe University, Graduate School of Agricultural Science, 1-1 Rokkodai, Nada-ku, Kobe, Japan; e-mail: naganot@ruby.kobe-u.ac.jp.

R. Kanber, Retired Professor, Çukurova University, Department of Agricultural Structures and Irrigation Engineering, Adana, Turkey; e-mail: kanber@cu.edu.tr.

S. Kapur, Retired Professor, Çukurova University, Department of Soil Science and Plant Nutrition, Adana, Turkey; e-mail: kapurs@cu.edu.tr.

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(3) To develop and improve the Regional Climate Model (RCM) for more accurate projection with higher resolution of future changes in a regional climate, as the base for better assessment of climate change impacts.
(4) To assess the vulnerability of agricultural production systems to natural change and to suggest possible and effective measures for enhancing the sustainability of agriculture through the integrated assessment of climate change impacts.

Keywords Adaptation · Agricultural production · Climate change
Impact assessment · Regional climate · Turkey

1.1 Introduction

The Assessment Report of IPCC WGII released in 2014 clearly identified the future risk of "loss of rural livelihood and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions" (IPCC 2014). This is one of eight key risks that have been identified with a high degree of confidence, spanning sectors and regions. Some fundamental questions are, however, raised and they include what exact impacts of climate change may manifest on irrigation and agricultural systems, how the systems can adapt to the changes, and what measures should be applied to sustain productivity.

Identifying the direction and dimension of potential impacts on irrigation and agricultural production systems, based on the projection of future regional climate change and consequent hydrological changes, is an essential process to adapt to them. The current structure and problems of the systems are also elucidated through analysing the impacts of climate change and developing adaptation measures.

To assess the climate change impacts on basin agriculture and its water use as its base, the analyses of the relationship between the climate and basin hydrology regime with water resources availability, and between water management and agricultural production of the basin are essential. These analyses or diagnoses involve various factors, which are often uncertain and inter-dependent. Therefore, integrated assessment needed to be developed for better projection and evaluation of climate change impacts as the basis for better adaptation.

While the "integrated assessment" is easier to establish in theory, it is, however, actually very difficult to develop and implement, since the behaviour and future statuses of the involved factors and players affecting each other are difficult to project in detail. Since this is a very implicit system, step-wise approaches with scenario-based projections are acceptable. These scenario-generating processes are useful when assessing the vulnerability of the present system.

In this chapter, first the general flow of this stepwise approach with scenario-based projection is outlined. Then, by way of example, a case study is introduced, this being the research project ICCAP that the authors of this chapter coordinated. Although the ICCAP was completed in 2007 and the authors have introduced this approach and outcomes of the project in several instances in the past (RIHN 2007; Watanabe 2012; Watanabe/Nagano 2014), its challenges are still considered novel and have not been elaborated in the context above. In this chapter, some additional information and modified points are highlight further developments in the study area. The main contents of this chapter are quoted from the presentation paper published in the proceedings of the 22nd ICID Congress (Watanabe/Nagano 2014).

Most of the following chapters of this book explain the details of its challenges in each part of the integrated approach overviewed here.

1.2 Step-Wise Integrated Approach to Climate Change Impacts Assessment

Figure 1.1 depicts the main flow of the step-wise integrated approach to climate change impacts assessment, including the adaptation measures evaluation. Hereafter each step, shown in the boxes of ‘A’ to ‘I’, is introduced briefly. The exact detailed processes or procedures are explained in the following case study section.

1.2.1 Step A

To project and assess future changes in water use and agriculture caused by climate change due to global warming, the target period or year in the future needs to be decided first and the future climate should be projected thereafter. Generally, future climate scenarios are best generated by outputs of *General Circulation Models* (GCMs) and/or outputs of Regional Climate Models (RCMs) nested with or downscaled from the GCM outputs. Then, future climate factors, including air temperature, humidity, radiation, wind, and so on, are provided as the basis of impact assessment. Taking the uncertainty of climate models into account, it is recommended that at least two models are used.

1.2.2 Step B

The basin hydrology model can simulate the future hydrological regime of the basin, with meteorological parameters provided by the climate scenarios. The outputs of the distributed process model include distribution of precipitation, evapotranspiration, seepage and other hydrological processes in each part of the basin, and finally river discharge at any point in the water system. Given the

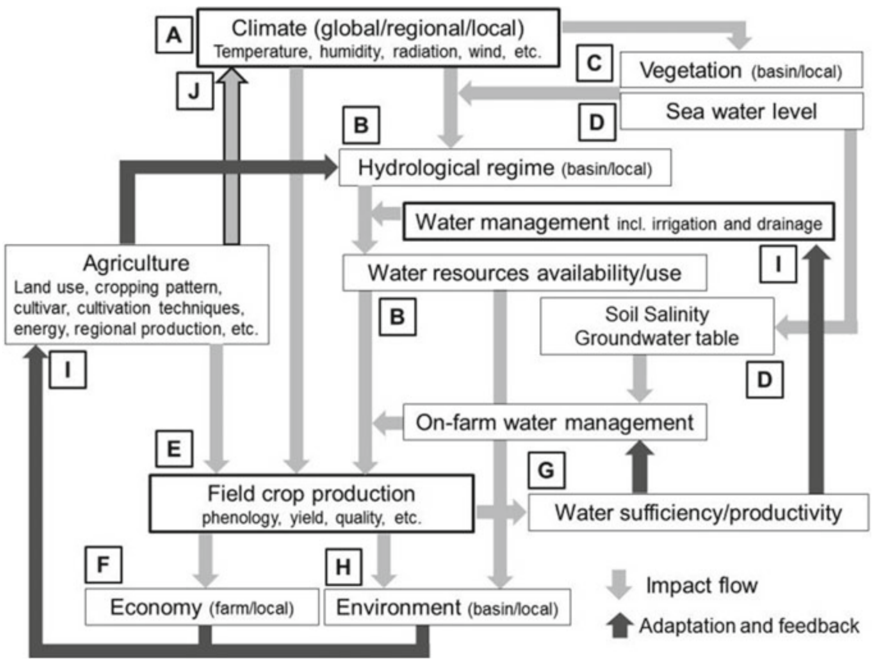


Fig. 1.1 Flow of the step-wise integrated approach to climate change impacts assessment. *Source* The authors

infrastructures for the management of water resources, such as reservoirs, ponds, diversion works and canals, and their operation rules, changes in the availability of water resources are predicted.

1.2.3 Step C

The vegetation model enables future land cover, especially vegetation, to be predicted by the projected meteorological parameters, which include future changes in the distribution of forests and species of trees and grasses. The transition of the vegetation, especially forest vegetation, takes longer and it should be noted that the future possible vegetation with future climate parameters is unlikely to be realised during the target period for which the future climate is generated. The change in vegetation should be reflected in the basin model.

1.2.4 Step D

When the target area is located in a coastal zone, the future sea level is generally projected simultaneously by the future climate. The projected sea level's impacts on the basin hydrological regime, including groundwater dynamics with seawater intrusion into the coastal region, are estimated. At this point the special groundwater dynamics model can be utilised in conjunction with the surface hydrology model. These models can provide predictions on groundwater availability and salinity.

1.2.5 Step E

Changes in crop growth and production in the fields are projected by many available crop models developed by many research organisations. In addition to the parameters of crop phenology, these projections require meteorological parameters and conditions of soil and water in the field, which might be provided in by steps A to D. In the initial phase this step assumes that a single crop is under cultivation in the current situation, since the future cropping pattern, which is affected by many un-redictable factors beyond the basin or region, cannot be projected.

1.2.6 Step F

Changes in crop production in the field affect farm economy and local/regional economics, leading to the alteration of cultivars, crops and cropping patterns. The changes in economics are estimated by specific micro and macro models developed in the field of agro-economics.

1.2.7 Step G

Comparing the future water availability provided by step B and the future water requirements calculated in step E may indicate possible water shortages in the water balance in the fields. For this estimation, any suitable model on field-level soil and water dynamics can be introduced. These changes in water productivity might be the basis for modified water management.

1.2.8 Step H

Future changes in, basin hydrology and water resources management, field conditions of soil, water and crop, and basin vegetation, might cause some environmental problems, including degradation of water quality, the eco-system and biodiversity. These changes need to be predicted. And, not only future changes but also present problems need to be diagnosed, since some measures to solve them need to be introduced when the adaptation measures to climate change are developed.

1.2.9 Step I

This step is for impact assessment with adaptation measures. With the outputs of steps A to H, the impacts of future climate change are projected. Here, the impacts do not mean just changes, but imply adverse effects with some damage. Assessment also implies not only prediction but also evaluation of the nature and extent of the problems.

To improve the future possible degraded situation, many alternatives will be proposed and compared before selection, since limited time and resources make it unfeasible to test all. Both modest and challenging adaptations should be used to predict the most likely or serious cases; in addition even undesirable cases could be tested, to identify what the stakeholders should be prepared for.

For example, in the case of a future water shortage prediction, expansion of the irrigation scheme may be proposed, and it would be considered undesirable for farmers wanting increased profits to introduce high water-consuming cash crops in the predicted conditions. In such a scenario, the construction of additional reservoirs or the introduction of improved management practices for efficient use are other options.

In this step, changes in land use and cropping patterns are the most usual options. Through these sets of counter measures and options, some adaptation scenarios are generated, as the assumption of future basin and agriculture.

1.2.10 Step J

This is not an adaptation process that can be recognised as the feedback of the basin to the climate system. Future conditions of the basin land use and cover, and the hydrological regime including the water content of the soil profile and evapotranspiration, affect the regional climate system. In most of the past and on-going impact assessments, these feedbacks are not involved, and are expected in the future with feasible conditions.

1.3 Trial Approach of the Integrated Impacts Assessment

1.3.1 General Overview

The step-wise integrated approach to climate change impacts assessment was tested in one of the research projects of Japan's Research Institute for Humanity and Nature (RIHN). The project was titled "The Impact of Climate Change on Agricultural Production System in Arid Areas (ICCAP)" and implemented from 2002 to 2007 in the case study area of the Seyhan River Basin in Turkey. Overviews of its concept, methodology and outputs have been previously published (RIHN 2007; Watanabe 2012), and in this chapter the processes of approach explained above are summarised according to their steps.

The main objectives of the project were:

i. To examine and diagnose the structure of land and water management in agricultural production systems in arid areas, and especially to evaluate quantitatively the relationship between cropping systems and the hydrological cycle and water balance in farmland and its environs.
ii. To develop a methodology or model for integrated assessment of impacts of climate change and adaptations on agricultural production systems, mainly on the aspect of land and water management.
iii. To assist the development and improvement of the Regional Climate Model (RCM) for more accurate prediction with higher resolution of future changes in regional climate.
iv. To assess the vulnerability of agricultural production systems to natural changes and to suggest possible and effective measures for enhancing the sustainability of agriculture through integrated impact and adaptive assessment of climate change.

1.3.2 Case Study Area: The Seyhan River Basin of Turkey

The research was implemented on the east coast of the Mediterranean Sea, mainly in the Seyhan River Basin in Turkey. Firstly, a comprehensive assessment of the basic and present structure of the agricultural production system was conducted with special reference to regional climate, land and water use, cropping pattern, and irrigation systems.

The Seyhan River Basin (Fig. 1.2) is dominated by a Mediterranean climate with winter precipitation. Rain-fed wheat is widespread in the upper hilly areas of the basin. Large-scale irrigated agriculture extends throughout the lower delta, where maize, citrus fruit, cotton, wheat, and vegetables are cultivated. These crops depend on water supplied by reservoirs that store the runoff of winter rain and snow in the upper mountainous areas.

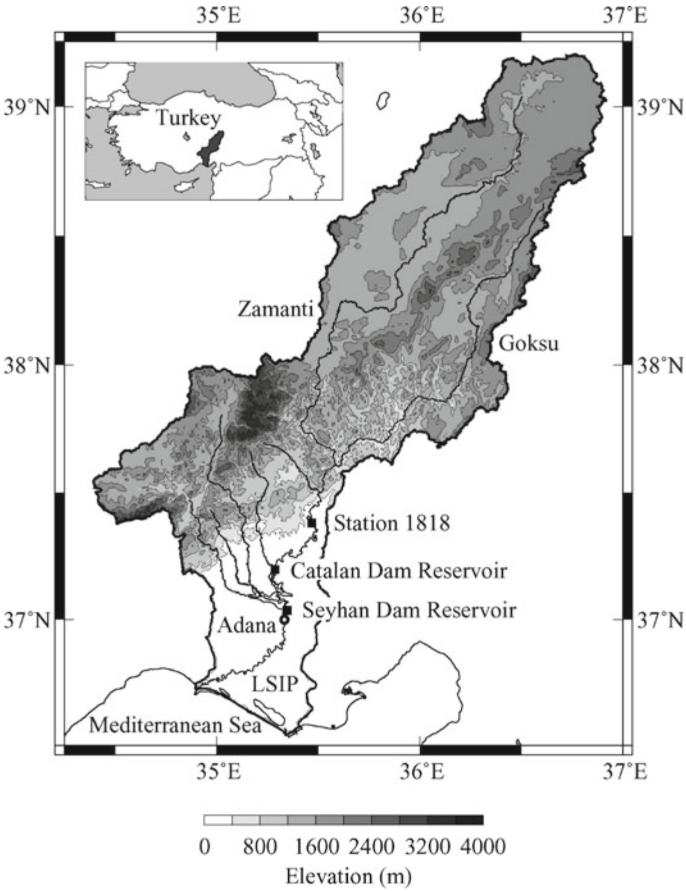


Fig. 1.2 The Seyhan River Basin of Turkey. *Source* RIHN (2007: 3)

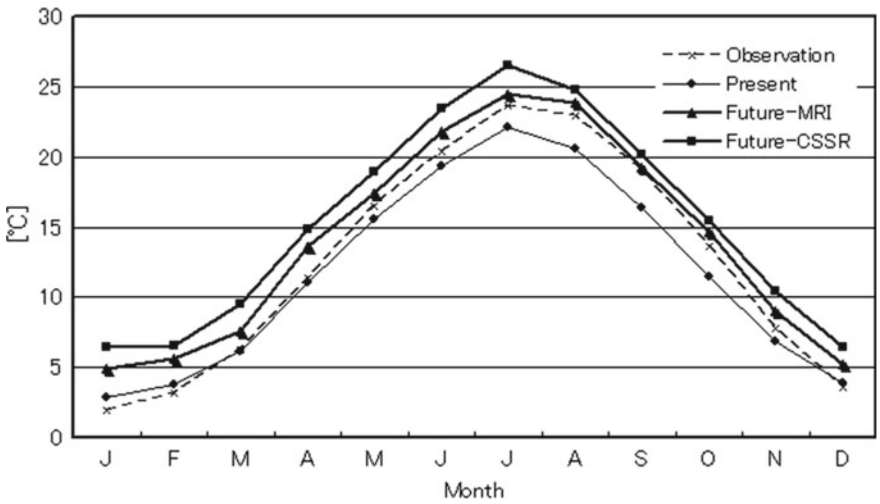
1.3.3 Climate Change Scenarios: Step A

The future climate change scenarios of the basin in the 2070s were generated by the two most advanced GCMs and one RCM with downscaling methods based on the A2 scenarios of the Special Reports on Emissions Scenarios by IPCC. Here, the A2 scenarios were used because the future considerable changes to the climate are assumed to predict many substantial impacts for identifying future problems. The outputs of the GCMs were downscaled for a ten-year climate scenario during the 2070s by 25 km grid intervals across the whole of Turkey and by 8.3 km grid intervals in the area covering the Seyhan River Basin. Two independent GCM projections were downscaled by only one RCM. Another GCM with a very high horizontal resolution was used as a reference to assess the reliability of the downscaling done in this research.

In the ICCAP, downscaling the outputs of the GCMs by the RCM was applied according to the state-of-the-art technology at that time for generating the local climate change scenarios. If finer resolution of local climate change is available, it is desirable to use it.

In the ICCAP project, a unique and innovative technique was developed for generation of the future local climate scenario to reduce the bias of the GCM outputs. It is called "pseudo global warming method" and its details are provided in the papers by Dr. Fujio Kimura and others, who developed and applied this practical solution (Sato et al. 2006; Kimura et al. 2007).

According to the generated scenarios, the surface temperature in Turkey may increase by 2.0 °C (projected using the GCM developed by the Meteorological Research Institute of Japan: MRI-GCM) and 3.5 °C (projected using the GCM developed by the Center for Climate System Research of University of Tokyo and the National Institute of Environmental Studies of Japan: CCSR/NIES-GCM). The total precipitation in Turkey may decrease by about 20% except in the summer. The projected trend of changes in temperature and precipitation in the Seyhan River Basin is similar to the changes in the whole of Turkey, while precipitation may decrease by about 25% (Fig. 1.3).



MRI: Meteorological Research Institute of Japan, CSSR: Center for Climate System Research, University of Tokyo

Fig. 1.3 Changes in monthly average temperatures in the Seyhan River Basin in the 2070s. *Source* Kimura et al. (2007: 27)

1.3.4 Hydrological Regime and Water Availability: Steps B, D and H

Precipitation in the basin is projected to decrease by about 170 mm, while evapotranspiration and runoff will decrease by about 40 mm and 110 mm respectively. Because of snowfall decreases and temperature rises, the snow amount will considerably decrease.

Compared to the present conditions, the decreased precipitation may cause a considerable decrease of inflow to the Çatalan and Seyhan reservoirs, in which the peak of monthly inflow might occur earlier than at present. Fewer flood events will occur under the warmer conditions.

The direct impact of future sea-level rise on groundwater salinity will not be serious, while increased evaporation and decreased precipitation with sea-level rise would cause a significant increase in salinity of the lagoon. Therefore, further groundwater withdrawal may result in saltwater intrusion. Build-up of a higher saline zone in the aquifer beneath the lagoon could cause water-logging on the land surface. Water-logging and increased salinity in shallow groundwater may cause salt accumulation on the land surface (Fujinawa et al. 2007).

In the project, environmental issues are not assessed. In the present, however, the river flow downstream of the diversion dam for irrigation is extremely low and would be increased according to the rising demand for conserving the ecosystem of the river in the future. Then, when the future impacts decrease the availability of water stored in reservoirs, the regulation of that so-called e-flow would be secured with the introduction of a guaranteed moderate discharge.

1.3.5 Vegetation: Step C

The actual and potential vegetation of the present were estimated using satellite images and field data. Areas of maquis and woodland with broadleaved evergreen trees of potential present vegetation were in practice occupied by field crops and Pinus brutia as secondary forest respectively. Areas of steppe and maquis will increase in the 2070s, while those of coniferous evergreen forests will decrease. The biomass of maquis and deciduous broadleaved woodlands will increase in the future and coniferous evergreen forests will markedly decrease, while the total biomass in the area will be only 45% of the present one.

1.3.6 Field Crop Production: Step E

Two crop growth simulation models were developed. The models projected that wheat and maize yields in Adana areas may increase at most by 15% from the current yield in the 2070s, whereas the simplified process model (SimWinc) (one of the models used) projected that wheat yields would decrease by 10% if the CO_2 concentrations were not incorporated in the estimate.

The yield estimated by two models suggests that the effect of elevated CO_2 almost offsets the impact of elevated temperature and reduced rainfall on wheat and maize grain yield. The global warming effects on wheat yield in Adana projected by both the wheat growth model and the economic model are around 13%, whereas other wheat growth model projections range between 25 and 37% (Nakagawa et al. 2007).

1.3.7 Economy: Step F and E

The econometric analysis estimated the climate change impacts on the production of wheat and barley and the farmers' economy and behaviour. Changes in crop yield were also predicted, together with the effects of prices, drought, high temperatures, and CO_2 concentrations. Changes in the sown area were predicted, together with the price and soil moisture effects. According to the predictions, the wheat and barley yields will decrease by 18% and 24% respectively in the 2070s with climate change. The area sown with wheat and barley will decrease slightly. Consequently, the total production of wheat will decrease by 3% and the production of barley will decrease by 13%. In addition, estimates in the case that Turkey becomes a member state of the EU show that the yield decrease of both of wheat and barley will be lower than the decrease if Turkey is not be admitted to the EU.

1.3.8 Water Sufficiency and Productivity – Irrigation and Drainage, Hydrological Regime and Water Resources Availability: Step G

The *Irrigation Management Performance Assessment Model* (IMPAM) was developed and validated in this research and was also applied to a small-scale monitored area in the Lower Seyhan Irrigation Project (LSIP). Using the IMPAM, the crop growth and water budget of the whole delta was simulated, and the results have revealed that irrigation demand in the future will increase due to an extended irrigation period. However, the change seems to be within the range of its adaptive capacity.

The water table was more sensitive to the degree of management than to climate change. In general, the risk of a higher water table seems less possible due to a projected decrease in precipitation and water supply. Waterlogging is predicted to partially occur along the coast (Fig. 1.4).

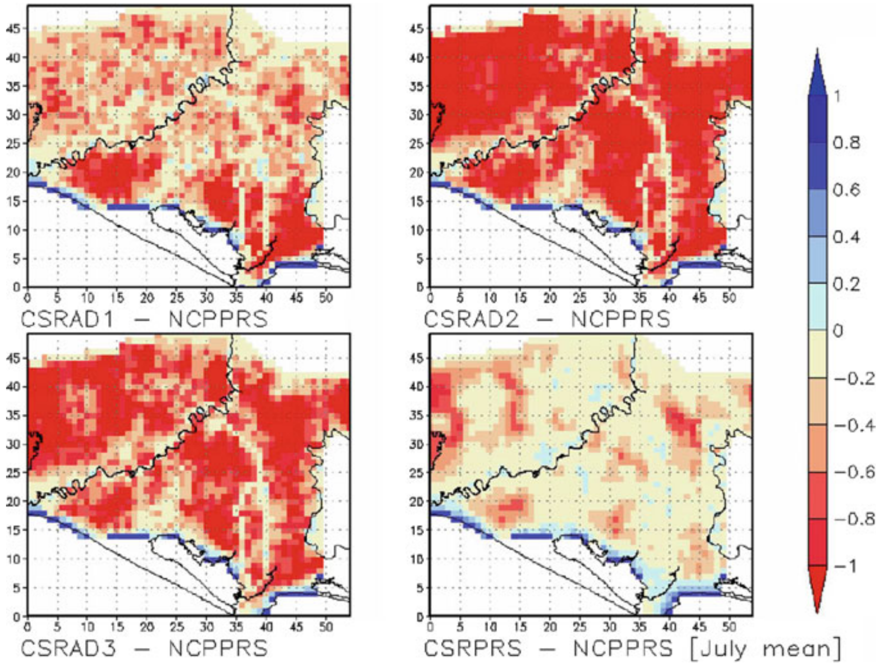


Fig. 1.4 Future changes in the water table in the Lower Seyhan Plain. The left-upper shows the changes with Adaptation 1, the left-lower with Adaptation 2, right-upper with Adaptation 3, and right-lower with the present situation, where the Adaptations are introduced in Step I (*Notes* These cases use CCSR/NIES-GCM). *Source* Hoshikawa et al. (2007: 228–229)

1.3.9 Adaptation in Agriculture and Water Resources Management: Step I

Future crops with future climate and reduced water availability are simulated first, using the expected value-variance (E-V) model. As land use would shift to more cash-generating crops than at present, the citrus area would remain constant at around 20% and, in the case of scarce water supply, watermelons would be grown in the 2070s. Watermelons are usually cultivated only once every five years to avoid replant failure (Umetsu et al. 2007)

Based on the results of impact prediction obtained in the study, the main features of the future conditions include less precipitation and water availability, increased irrigation demand, and expansion of vegetable production. The following three Adaptation Scenarios – No. 1 to 3 – are generated, covering the cropping patterns and the management of land and water use. In these scenarios the future basin conditions are assumed to be continuations of the present land use and water management system as well as the cropping pattern. Moreover, all four cases are simulated with future climate scenarios.

- Adaptation No. 1: Passive and lower investment, with reduction of rain-fed wheat in upstream.
- Adaptation No. 2: Active and higher investment, with expansion of irrigation in mid-stream and lower delta, dam construction, and enhanced irrigation efficiency.
- Adaptation No. 3: Higher investment, with expansion of irrigation in mid-stream and lower delta, and increased groundwater use in the delta.

With these adaptation scenarios, the future situation is projected and the impacts are assessed. The expansion of irrigated land in the middle basin with increased water demand and decreased river flow could lead to water scarcity for the lower plain of the basin, as shown in Fig. 1.5. Here, 'reliability' is defined as "water supply/water demand", that is an indicator to show how much the demand is

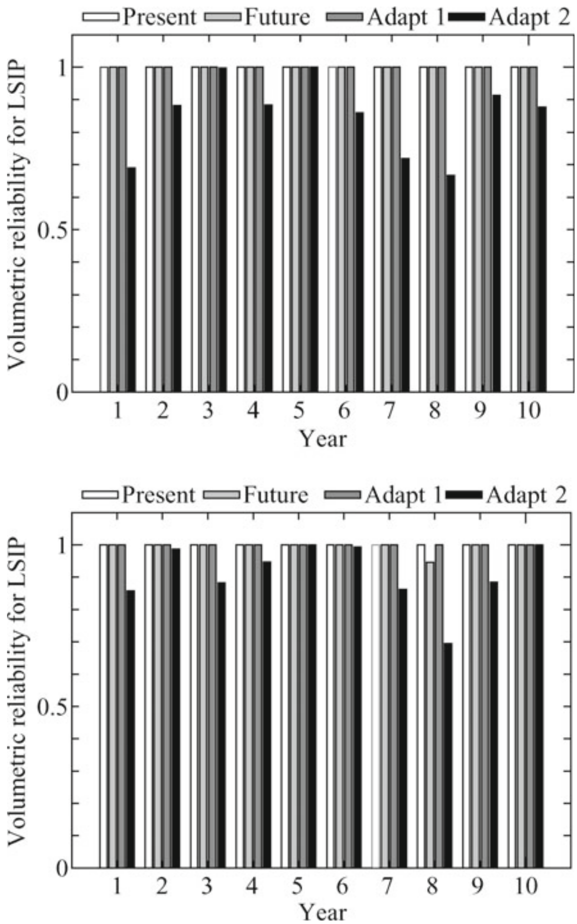


Fig. 1.5 Changes in water resources reliability (Top: by MRI-GCM, Bottom: by CCSR/NIES-GCM. Adapt 1 and 2: Adaptation Scenario No. 1 and No. 2). *Source* Fujihara et al. (2007: 94)