

A Systematic Evaluation of Climate Services and Decision Support Tools for Climate Change Adaptation

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ABSTRACT

Climate services, often refers as decision support tools, are developed to provide information with a view to aid in decision making and policy planning for adaptation due to climate variability and change. This study investigated different publicly available climate services and decision support tools based on previously proposed evaluation framework. This evaluation framework originally consists of four design elements which are divided into nine evaluation metrics for this study. These evaluation metrics are: identification of decision making context, discussion of the role of climate information in decision making, discussion of non-climatic factors, uncertainty of the data presented, accessibility of information, discussion on the development process, sustainability/ ongoing process, discussion of funding sources, and evaluation of the tool through survey, modeling or contingent valuation method. Tools were then given “High”, “Medium”, and “Low” score for each of the criterion. A total of 19 tools were evaluation for this study. Tools performed relatively well in “characteristics, tailoring, and communication of the climate information” and “governance, process, and structure of the climate service” whereas they got average scores in “problem identification and the decision-making context” and “value of the service provided”. Additionally, four case study evaluation of tools showed detail evaluation of how the tools performed against each of the criterion. The results of this study showed the relative strengths and weakness of the evaluated tools which can be used to improve existing climate services to aid in adaptation decision needs for climate change. This will also help in better decision making and policy planning for different sectors impacted by the changing climate.

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GENERAL AUDIENCE ABSTRACT

Climate services, often refers as decision support tools, are developed to provide information with a view to aid in decision making and policy planning for adaptation due to the adverse impacts caused by climate variability and change. This study investigated a total of 19 publicly available climate services and decision support tools based on previously proposed evaluation framework. This evaluation framework originally consists of four design elements which further classified into nine evaluation metrics and each of tools were given “High”, “Medium”, and “Low” score against these criteria. These metrics are: identification of decision making context, discussion of the role of climate information in decision making, discussion of non-climatic factors, uncertainty of the data presented, accessibility of information, discussion on the development process, sustainability/ ongoing process, discussion of funding sources, and evaluation of the tool through survey, modeling or contingent valuation method. Evaluated tools performed better than average in terms of uncertainty of the data presented, accessibility of information, discussion on the development process, sustainability/ ongoing process, discussion of funding sources, and feedback/ evaluation criteria whereas they performed below average in problem identification and decision making context, discussion of the role of climate information in decision making, and discussion of non-climatic factors. Four case study evaluation were also presented in this study for better understanding of how the evaluation process works for the tools. The results of this study provide an insight about the relative strengths and weakness of the evaluated tools and these can be used to improve existing climate services tools. This will also help in better decision making and policy planning for different sectors that are being impacted by the changing climate.

Dedicated
to
MY BELOVED FAMILY
my lifeline and the greatest strength

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Table of Contents

List of Figures	viii
List of Tables	ix
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background of the Study.....	1
1.2 Objectives of the Study	3
1.3 Organization of the Thesis	3
CHAPTER TWO: LITERATURE REVIEW.....	5
2.1 Introduction	5
2.2 Climate Services.....	5
2.2.1 Development of Climate Services	7
2.2.2 Important Aspects of Climate Services.....	10
2.3 Evaluation of Climate Services	12
2.3.1 Different Frameworks for Evaluation of Climate Services	13
2.3.2 Existing Evaluations of Climate Services.....	15
CHAPTER THREE: METHODOLOGY	18
3.1 Introduction	18
3.2 Selection and Definition of Evaluation Metrics.....	20

3.2.1	Problem Identification and Decision Making Context	24
3.2.2	Characteristics, Tailoring and Communication of Relevant Information.....	24
3.2.3	Governance, Process and Structure of the Service	25
3.2.4	Value of the Service Provided	26
3.3	Selection of Clearing Houses	26
3.4	Selection of Tools.....	28
3.5	Selection of Case Study Tools for Detail Study	28
CHAPTER FOUR: RESULTS AND DISCUSSIONS.....		33
4.1	Introduction	33
4.2	Evaluation of the Tools	33
4.3	Detail Evaluation of Case Study Tools	40
4.3.1	Case Study 1: Surging Seas Risk Finder.....	41
4.3.2	Case Study 2: Climate Explorer 3.0.....	45
4.3.3	Case Study 3: Future Crop Suitability	48
4.3.4:	Case Study 4: Water Supply Stress Index (WaSSI).....	51
4.4	Limitations of the Study.....	54
4.5	Recommendations for Future Study	54
CHAPTER FIVE: SUMMARY AND CONCLUSION		56
Bibliography		59

List of Figures

Figure 2.1	A schematic illustration of the five pillars of the GFCS	9
Figure 3.1	A schematic diagram of methodology of the study	19
Figure 3.2	Methodological framework showing the selection of the climate services tools for the study	27
Figure 4.1	Stacked bar chart showing number of low, medium and high scores for each of the nine evaluation criteria	39

List of Tables

Table 2.1	Some existing climate services providers	11
Table 3.1	Definition of the evaluation metrics based on the evaluation framework proposed by Vaughan and Dessai	21
Table 3.2	List of the climate service tools selected for the study	29
Table 4.1	Evaluation of the tools for each of the nine evaluation criteria	36

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Climate services refer to spatial and temporal climate data provided by different institutes and organizations to aid decision-making in various fields, such as agriculture and food security, water resources, health, energy, disaster risk reduction, and human security (Vaughan & Dessai, 2014). Sometimes referred to “decision support tools”, they include information on average weather based on observed climate data over various temporal scales (Vaughan & Dessai, 2014), as well as future climate projections with a view to help in decision support for climate change adaptation (Adams et al., 2015). Climate services do not focus on climate data solely. A good climate service must provide information that addresses problem identification for decision making and policy making for climate change adaptation and mitigation; this requires looking for the needs of end user (Bessembinder et al., 2019; Goddard, 2016).

The development of climate services is linked to the development of climate science. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Climate Observing System were formed to improve climate observation, prediction, impact assessment and services. The third World Climate Conference (WCC 3) recommended a Global Framework for Climate Services (GFCS) in 2009 with a vision for better climate services, especially in developing countries; this framework was first implemented in 2011 (Vaughan, Buja, Kruczkiwicz, & Goddard, 2016). The concept of climate services was developed to provide information in response

to climate variability and change as well as to increase human security in terms of disaster risk management. However, it needs to be focused on a specific problem and originated from good-quality observations to successfully support adaptation or mitigation decision making (Goddard, 2016). Any particular region or sector is influenced by the continuous change of climate; hence the temporal variation (both historical and future projection information) in climate plays an important role in risk assessment and decision support. The importance of climate services also depends on spatial variation i.e. he observes historical weather information, short term forecast and future climate projections as the magnitude or intensity of any climate data is not the same across the globe. Hence for proper decision making, it has to give proper information for a specific location (Goddard, 2016).

With the advancement of climate services, different criteria were also developed to evaluate the effectiveness of climate services. For example, Vaughan & Dessai (2014) suggest four design elements for a climate services evaluation framework: problem identification and decision-making context; characteristics, tailoring and communication of relevant information; governance, process and structure of the service; and socioeconomic value of the service provided. Another evaluation structure is the Global Framework for Climate Services (GFCS) which consists of five pillars for better evaluation of climate services. These are a user interface platform; climate services information systems; observations and monitoring; research, modeling and prediction; and capacity development (Vaughan et al., 2016). Integrity, transparency, humility, and collaboration are the core elements of another ethical framework for evaluation of climate services related to human security and risk management (Adams et al., 2015). While multiple frameworks for the evaluation and improvement of climate services have been proposed, little research exists that

evaluates how well existing climate services meet these criteria. Vaughan, Dessai, and Hewitt (2018) provided a bird's-eye view of more than 100 climate services based on the information available in 2012 highlighting a general snapshot the services provided by the providers. However, detail evaluation of any specific tool in terms of how well they are doing in providing information to the user group is not available in literature.

In this study, the evaluation of the existing climate services was conducted by following by the design elements provided by Vaughan and Dessai (2014) and evaluate them into high, medium and low categories based on the evaluation metrics.

1.2 Objectives of the Study

The principal objective of this study is to evaluate multiple climate services tools to determine how effectively they meet previously-proposed evaluation criteria. Specifically, the aim is to achieve the following objectives:

- Investigate systematically different publicly available climate services/decision support tools with an emphasis on climate change risk management and adaptation following a previously proposed evaluation framework.
- Evaluate the degree to which an individual climate service tool meets the proposed evaluation criteria and suggest areas for broad improvement.

1.3 Organization of the Thesis

This thesis has been divided into five chapters which have been outlined below.

Chapter one discusses a brief background of this study along with the objective of the study.

Chapter two provides a brief introduction and evolution of the climate services and discusses different frameworks of evaluation of climate services.

Chapter three elaborates the steps and processes required for the evaluation of publicly available climate services for this study.

Chapter four discusses the results of the evaluation work for this study. It includes the evaluation of 19 climate services tools and four case study tools. It also includes discussion of the limitations of the study and some future recommendation.

Finally, chapter five provides the summary and conclusions for this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

With the development and increasingly widespread use of climate services, different evaluation criteria have been proposed to assess how well climate services support decision making and suggest ways to make them more effective. This chapter presents different conceptualizations of climate services which are often referred to as decision support tools. Emphasis is given to different frameworks developed for the evaluation of existing climate services tools and ways to improve them.

2.2 Climate Services

The concept of climate services was developed to provide various information in response to climate variability and change, ultimately increasing human security and supporting risk management. It involves the production, translation and delivery of climate information with a view to aid in decision making and policy planning (Vaughan, Buja, Kruczkiwicz, & Goddard 2016). Additionally, climate services aim to help in adaptation strategies and reduction of climate induced risk and vulnerability by providing the most recent information on climate science to its user groups (Climate Services Partnership 2015; Vaughan & Dessai 2014; WMO 2019).

Adams et al (2015) defined climate services as the type of services that are related to spatial and temporal variability of climate data, information and knowledge base in various climate related

fields as well as sectors of application. (Jancloes et al (2014) highlighted that these services can be provided by public and private organizations and specialist institutes. This information can help in decision making for climate change adaptation. Climate services is different from typical weather information by providing various temporal scale data that are generated by using different methods of analysis, such as time series data analysis and statistical analysis (Vaughan & Dessai 2014). Climatic information can be either historical information or future projections. Climate services information are intended to help in decision making in for adaptation and mitigation strategies for both developed and developing world (Asrar, Ryabinin, & Detemmerman 2012).

Vaughan & Dessai (2014) described climate services of any form of climatic information for providing timely and tailored information and knowledge to decision makers for aid in decision making. Climate services are developed from climatic and weather data sets and sometimes include other related information, such as socio-economic information. This information can be obtained from global, regional, or local observations or downscaled from larger scale information. Goddard (2016) emphasized the development of climate system that includes the time scale of a future projection for development of climate services which affects in decision making process.

Brooks (2013) referred climate services as the practical application of climate research to help people manage climate-related risks and prioritize investment on favorable conditions giving focus on long-term decision support as well as on early warning systems. He also identified three E's to bridge the gap between the climate research and its application in the form of climate services. These the E's are: engagement (i.e. the partnership between the service provider and its user), entrepreneurship (i.e. being innovative to create new with the limited resources) and evaluation

(i.e. the performance metrics for self-evaluation and self-improvement from the developer of the climate services).

The aim of climate research is to provide insight and allow for critical thinking about climate models, projections although it does not provide information to assist directly with adaptation and mitigation efforts. On the other hand, climate service emphasizes on the delivery of up to date information to various user group with a view to help in understanding of climate systems and helping to prepare for adaptation and mitigation due to changing climate (Vaughan & Dessai 2014; WMO 2012; WMO 2019). At the same time, Clifford, Travis, and Nordgren (2020) emphasized on the importance of local peoples' perception which might play a significant role in determining the acceptability of climate services among local people in a specific area.

2.2.1 Development of Climate Services

The development of climate services is inked with the development of climate science. During late 19th century, the World Meteorological Organization (WMO) started working with the International Meteorological Organization (IMO) with an aim of developing a framework for international cooperation on climate research and data exchange.

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Climate Observing System was formed for improvement of climate observation, prediction, impact assessment and services in the government level of the countries. In 2009, after the third World Climate Conference, the Global Framework for Climate Services (GFCS) was established for better management of risk and vulnerability due to climate change. The principle focus of the development of GFCS was to guide the development of climate services, especially in developing

countries. But it took two more years to be finally implemented in 2011 (Vaughan et al 2016; WMO 2012).

At present, the main focus of climate services is to provide information on seasonal forecasts for decision making, along with long term projections for policy making, strategic planning, and disaster risk reduction. Presently various sectors are receiving benefits from climate services, including agriculture and food security, water resources, health, energy, disaster risk reduction, and human security (Vaughan and Dessai, 2014). Climate services also uses expertise form some social sciences fields, which may include political science, sociology, anthropology, and economics (Vaughan et al., 2016).

Global Framework for Climate Services (GFCS)

The Global Framework for Climate Services (GFCS) was formed in 2009 by the international community in 2011 (WMO 2012). It was an outcome of the third World Climate Conference, with a vision to guide the development of climate services especially for the developing world and for people who are at a bigger risk under a changing climate. Additionally, it was envisioned as a method for supporting better management of climate change, variability, and associated risks on society, development of adaptation and mitigation strategy, development and incorporation of science-based climate information into planning and policy formulation. It has applications at various spatial scales of interest including global, regional, and national.

GFCS has five different components, often referred as the “five pillars of GFCS”, which are: User Interface Platform, Climate Services Information System, Observations and Monitoring, Research,

Modelling and Prediction, and Capacity Development. The effectiveness of these five pillars are dependent on the interaction among them which shown in Figure 2.1.

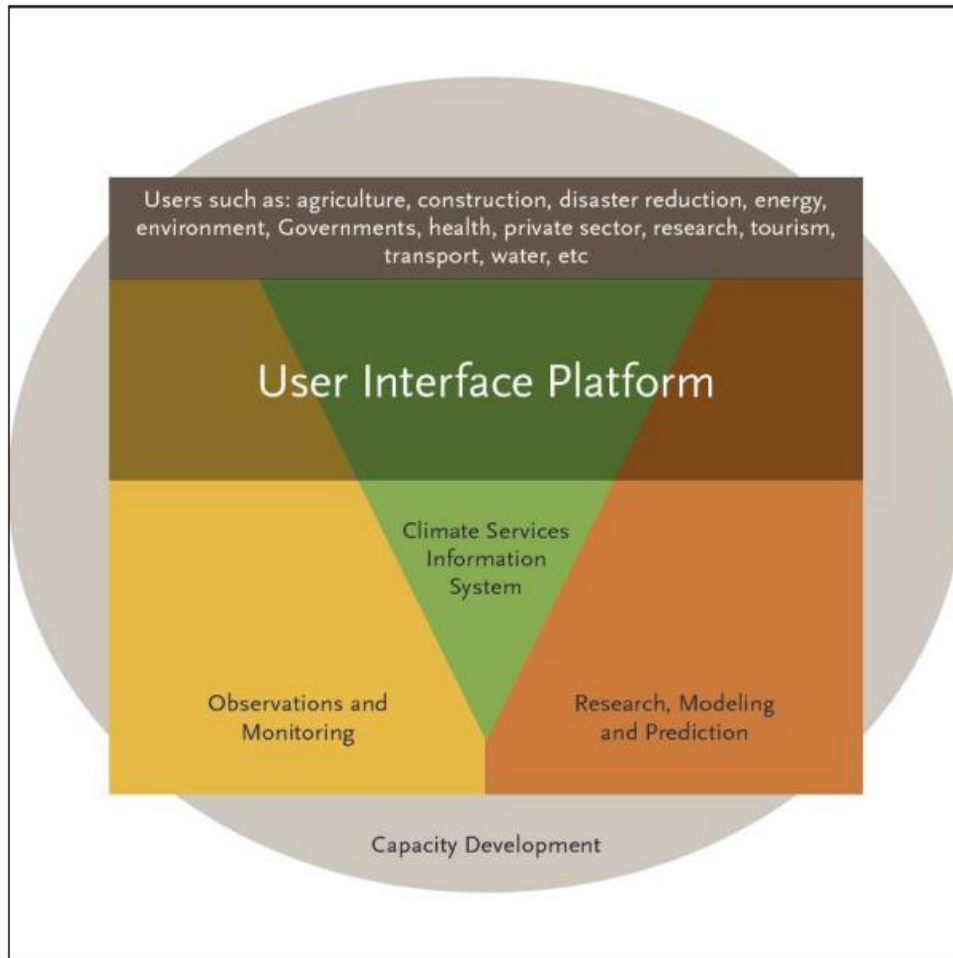


Figure 2.1: A schematic illustration of the five pillars of the GFCS (*Source: WMO 2012*)

GFCS focuses on five priority areas: agriculture and food security, disaster risk reduction, energy, health and water. It provides information on various projects in these areas. It helps in finding information on climate and non-climate data to help better decision support for climate change adaptation planning. Developed countries are expected to share climate data, expertise while the developing countries are encouraged to take benefits from GFCS partners.

2.2.2 Important Aspects of Climate Services

The concept of climate services was developed to provide various information in response to climate variability and change due to changing climate, to increase human security in terms of disaster risk management. However, it needs to be focused on a specific problem, originate from good-quality observations, and focus temporal variation to be successful (Goddard 2016).

Temporal variation of climatic information is important because of the continuous nature of climate. Any particular region or sector is influenced by the continuous change of climate hence the temporal variation of climatic information plays important role in risk assessment and decision support system. The importance of climate services also varies with the spatial variation of location as the magnitude or intensity of any climate data is not same across the globe. Hence for proper decision making, it has to give proper information for different location (Goddard 2016).

Climate services are provided by various types of organizations, including government, private, local, international, and specialty institutions to some extent. These organizations provide climate information on various spatial and temporal scales. Table 2.1 presents an overview of some of the key international climate services. On a national level, centrally funded organizations provide climate information and relevant impacts of climate change on the environment, economy, and society to stakeholders at national and local levels in different countries. Although this is available mostly in developed countries, some authors have suggested the importance of initiating similar services in developing countries as well (Vaughan & Dessai, 2014). Regional climate service providers provide climate information for any region that is mostly different in physiographic, economic and climatic characteristics. In addition to these types of service providers, academic and research institutes are also playing significant role in climate services around the world.

Table 2.1: Some existing climate services providers

Climate services provider	Country	Scale	Website
World Meteorological Organization (WMO) Climate Services	International	Global, Regional	http://www.wmo.int/pages/themes/climate/climate_services.php
Food and Agriculture Organization of United Nations (FAO) Climate Change Resources	International	Global, Regional	http://www.fao.org/climatechange/59898/en/
Red Cross Climate Center	International	Global (developing countries)	http://climatelab.org/Red_Cross_Red_Crescent_Climate_Centre
NOAA (National Oceanic and Atmospheric Administration) Climate Services Portal	USA	Global, Regional, National	https://www.climate.gov/
Australia National Climate Centre	Australia	Global, Regional, National	http://www.bom.gov.au/climate/
China Meteorological Administration (CMA) Climate	China	Regional, National	http://www.cma.gov.cn/en2014/
UK MET Office—Climate Services	UK	Global, Regional, National, Local	https://www.metoffice.gov.uk/services/research-consulting/climate-service
KNMI Climate Services	Netherlands	National, Local	https://www.knmi.nl/research/climate_services/
Climate Service Center, Germany	Germany	Global, Regional, National, Local	https://www.climate-service-center.de/
Southern African Development Community Climate Services Centre (SADC CSC)	South Africa	Regional, sub regional	https://www.sadc.int
Caribbean Community Climate Change Centre (CCCCC)	Caribbean Community	Regional, National	http://www.caribbeanclimate.bz

Source: Modified from (Medri, Banos de Guisasola, & Gualdi, 2012)

Climate services can be beneficial at various forms, including the individual level, collective or community scale, as well as on various sectors of society. For example, in the agricultural sector, climate information may give early warning to farmers about potential threats to crop production. It can also give information about potential natural hazards and adaptive precautions that can be taken accordingly.

2.3 Evaluation of Climate Services

Climate services are intended to aid in decision making in terms of climate adaptation, mitigation and policy planning in variety of user groups and sectors including water and food security, natural resources management, health services, engineering and planning (Webber, 2019). However, with the growing interest on the use of climate services there is active discussion how well the climate services are serving the needs of its user groups (Vaughan et al., 2018). Hence the need for evaluation of the services come into question.

With the advancement of climate services, different criteria were also developed to evaluate the effectiveness of climate services because of the necessity to make proper evaluation of the service they provide. For example, there are some design elements for a climate services evaluation framework, i.e. problem identification and decision making context; characteristics, tailoring and communication of relevant information; governance, process and structure of the service and socioeconomic value of the service provided (Vaughan & Dessai, 2014).

Since climate services are related to human security and risk management, an ethical framework for evaluation of climate services was also developed (Adams et al., 2015). Integrity, transparency, humility, and collaboration are the core elements of this ethical framework. These principles

should be considered as the minimum requirements by the service providers and the users of climate services should also review these.

Buontempo et al (2018) provided a critical analysis of five climate services developed under the EU funded project EUPORIAS. He summarizes some key points for the climate services developers and funding agencies which includes a strong interaction between the developer and user in the development stage, discussion between the developer and the user and flexibility to incorporate changes from user feedback, and tailoring of information based on user needs.

Brasseur and Gallardo (2016) identified some barriers to the success of climate services. These includes inadequate awareness among the public and policy planner about the consequences of changing climate in future, lack of relevant research and services by the scientific community, inappropriate format of the information provided by the service providers, insufficient business model to understand the economic value of the climate services and associated policy changes for adaptation and mitigation.

2.3.1 Different Frameworks for Evaluation of Climate Services

Climate services are a powerful tool in a constantly changing world where climate change is creating multi-dimensional risk and vulnerability for people around the world. Climate services need to provide information to its user community to aid in better decision making to adapt with the changing climate and reduce risks and vulnerability associated with future climate change. However, researchers and practitioners have recognized the need for more specific frameworks and guidelines on how climate services should be developed to be most effective. While multiple

evaluation frameworks have been proposed, they have not yet been widely applied in the evaluation of existing climate services.

Climate Service Evaluation Framework Proposed by Vaughan and Dessai (2014)

Vaughan and Dessai (2014) proposed four design elements for evaluation of climate services which are compiled after extensive review of literature available on that time. These four elements are broadly described as follows.

- 1) Problem identification and decision making context
- 2) Characteristics, tailoring and communication of relevant information
- 3) Governance, process and structure of the service
- 4) Value of the service provided

Problem identification and decision making context is important to understand the usability of the climate service information provided by the developer. Mentioning a specific context makes it easier for users to understand how it can be used for making any decision related to climate change risk management. It can give a broader perspective to its users if there is any political, ethnic or gender influence in the information they provided (Archer, 2003). At the same time, discussion of climatic and non-climatic information gives its user group better understanding of how different types of information available within a tool can be used to make better decisions in deciding upon adaptation strategies.

The success of the climate services is highly dependent on how well they are communicating with the user group. Hence, characteristics, tailoring and communication of relevant information is very important element to define the success of any decision support tool. Another important aspect of

the evaluation framework proposed by Vaughan and Dessai is how well the tools are doing in terms of maintaining effective communication, transparency, and flexibility between service provider and user groups which is the third design element of the framework. Finally, an effective climate services tool should provide an economic and/or social value to its users by providing options to feedback from user end and incorporating those feedbacks for improvement of the service they provide. Zahid et al (2020) also emphasized the importance of quality assurance of the data provided and evaluation through survey for the climate service to be successful.

An Ethical Framework for Climate Service (Proposed by Adams et al 2015)

Adams et. al (2015) proposed an updated ethical framework for developing climate systems with four core elements focusing integrity, transparency, humility, and collaboration. In this framework integrity refers to the conduct of practice which is important to suppress personal interest, commercial pressure to gain economic or personal benefit; which are very important to maintain the transparency of the climate services. At the same time, transparency is important to gain the trust of the user community. If the development, funding, or data behind a tool is not clearly stated, this can lead to the failure of trust between the service provider and the user community. Humility refers to the commitment of providing exact information to the user community by maintaining honesty and integrity. Collaboration is considered as the cornerstone of climate services by Adams et. al (2015). The better the collaboration between the researchers, government and non-government officials and civil society the better service can the developer provide to its users.

2.3.2 Existing Evaluations of Climate Services

Vogel, Letson, and Herrick (2017) described an elaborated logic model for the evaluation of climate services in a case study of the Caribbean Agrometeorological Initiative (CAMI) in the

Caribbean agriculture context. In this logical model they formed an idealized Weather service chain analysis (WSCA) which evaluated the effectiveness of the CAMI program. This evaluation work was more like the development of a logical connection among different components of climate services to make it successful.

Tall, Coulibaly, and Diop (2018) showed a case study evaluation of climate services available for farmers in Africa. This study provided some insight on evaluation of the existing climate services and focused on the impacts of climate services to be distinct among the outputs, outcomes and impacts.

Vaughan et al (2018) provided a snapshot of about 101 existing climate service providers around the world and how they are performing based on the evaluation framework proposed by Vaughan and Dessai (2014). In this study, they considered the tools available until 2012. Location of the climate services provider, what sectors to the climate services addressed, location specific climate services, target user group and organizations of the climate services, temporal variability of the information provided, quality of the information provided, user feedback, spatial variability of the target user group, communication with the user group, funding sources, and the evaluation methods are the questions addressed in this study. However, this study lacked in evaluation of any specific tool based on evaluation criteria.

Cortekar, Themessl, and Lamich (2020) analyzed 371 climate services providers in the European Union states to generate a portfolio of the existing climate service providers. This study focused mainly on the geographic distribution of the climate service providers. It also highlighted on the

service provider (whether public or private organization), whom the service is being provided, what information they are providing etc.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

In this study, we compare 19 climate change adaptation decision support tools based on the evaluation criteria proposed by Vaughan and Dessai (2014). The proposed evaluation framework is related to four factors that impact the success and benefits of climate services. These four factors are further divided into nine evaluation metrics to assess the extent to which individual climate services, climate service providers, and/or climate services in general live up to their promise.

- 1) Problem identification and decision making context
 - a) Identification of decision making context
 - b) Discussion of the role of climate information in decision making
 - c) Discussion of non-climatic factors
- 2) Characteristics, tailoring and communication of relevant information
 - a) Uncertainty of the data presented
 - b) Accessibility of information
- 3) Governance, process and structure of the service
 - a) Discussion on the development process
 - b) Sustainability/ ongoing process
 - c) Discussion of funding sources

4) Value of the service provided

- a) Evaluation of the tool through survey, modeling or contingent valuation method

For the selection of climate services tools, initial clearing houses were selected based on literature review and developing organizations which led to the selection of the 19 tools evaluated for this study. A schematic diagram of the methodological process of the study is shown in Figure 3.1.

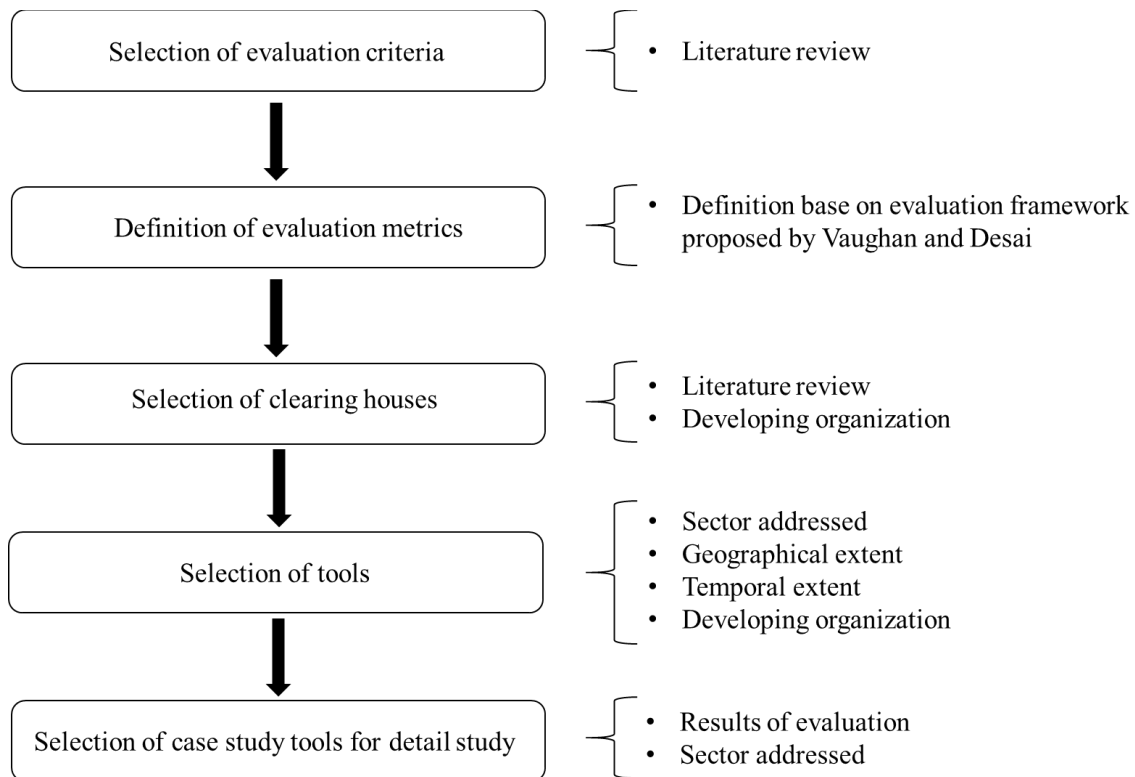


Figure 3.1: A schematic diagram of methodology of the study

Climate services provide various climate information to its users with historical information and uncertainties or confidence in projected information. The accuracy of the information is highly dependent on the spatial and temporal scales of analysis along with varying levels of uncertainty (Donnelly, Ernst, & Arheimer, 2018). Many climate services and decision support tools are

available online, and they vary widely in terms of the sector, spatial area, and temporal period addressed. To make the comparison across tools more straightforward, we used several selection criteria to identify tools that were fairly similar in terms of the information provided and questions addressed. We selected tools that addressed the water, agriculture, and natural hazards sectors. In terms of the spatial extent of the information provided, we identified tools providing information for the contiguous US or the coastal US. Since this evaluation work focused on climate change adaptation, we selected the tools that provide information on future climate change and sea level rise, including long term climatic projections, rather than historic data or short-term forecasts. Another criterion for tool selection was the developing organization. In this study, we primarily focused on tools developed by federal organizations.

Relative strengths of these tools and services were discussed based on the nine evaluation criteria mentioned above and each of the tools are categorized as scoring High, Medium, or Low for each criterion. Four case study evaluations were performed to provide a detailed discussion of how well these tools meet the evaluation criteria.

3.2 Selection and Definition of Evaluation Metrics

Vaughan and Dessai (2014) proposed four general design elements for the evaluation of the climate services to evaluate how effectively these tools are maintaining different aspects of the performance of climate services. For our evaluation, we used these four design elements to identify nine evaluation metrics that could be used to structure the comparison across multiple tools. A rubric was created that defined characteristics for high, medium, and low scores for each evaluation metric. A definition of each of the evaluation metrics, along with the characteristics defining high, medium, and low scores, is given in Table 3.1.

Table 3.1: Definition of the evaluation metrics based on the evaluation framework proposed by Vaughan and Dessai (2014)

Column name	Explanation of metric	Possible results
Problem identification and decision making context	Climate services are aimed to help in decision making in specific contexts with assumptions that are naturally involved with these contexts. To do so, it needs to provide information about relevant climate variability for each individual context.	Low - no information on relevant decision context identified
		Medium - Some general information on decision context given, but few details or specifics
		High - detailed and/or specific information given on decision context
Discussion of the role of climate information in decision making	Climate services are based on assumptions about how climate information can support decision making. Climate is rarely the only factor that influences decision making, but it may be more or less important in different contexts. Does the tool discuss how climate information could help decision making and how it relates to other factors that influence climate risks?	Low - no discussion on the role of climate information in decision-making
		Medium - some general information on the role of climate information in decision making is provided
		High - specific information and/or examples on the role of climate information in decision making is provided
Discussion of non-climatic factors	Climate services may provide information about socioeconomic condition e.g. population, infrastructure, livelihood etc. that will be affected in changing climate.	Low - only weather related information provided
		Medium - Only population information available as non-climatic parameter
		High - multiple non-climatic information provided with relevant scale of intended use
Uncertainty of the data presented	Climate models, as well as the climate observations that are used to develop and drive climate models, are inherently uncertain. We cannot predict with perfect accuracy what future temperature, precipitation, or sea	Low - some qualitative information or text is included to inform users that projections are uncertain; information is available in the supporting document.
		Medium - Limited quantitative information available with one or two climate scenarios within the tool.

	level will be. Climate services should acknowledge this uncertainty and present it where relevant.	High - quantitative information on uncertainty (such as ranges, multiple (more than two) projections, or probabilities) is included in the tool.
Accessibility of information	The success of climate service is dependent on the quality, and accessibility of the information provided. It needs to be well presented and easily interpretable for non-experts.	Low - challenging to understand. Basic explanatory information (e.g., legend or scale) is either unprovided or difficult to find. No examples or explanation on how to use the tool are included.
		Medium - Basic explanatory information is included, but no examples or detailed explanations are provided.
		High - relatively easy to understand. Basic explanatory information is included and clear, and examples or detailed explanations are included, easy to find, and clear.
Discussion on development process	The development process of the information needs to be mentioned for better understanding of the organizations and steps involved in creating the tool. It will also help make the tool's background more transparent.	Low - No information available
		Medium - Information available through supporting documents but it is not clearly labeled or easy to find.
		High - information available in the supporting documents is clearly labeled and easy to find.
Sustainability/ ongoing process	Ideally, the information presented in climate services should be regularly updated when new information or projections become available. The tool should present information about the dates when it was developed so that users can see how current the information is, and describe if the information is regularly updated.	Low - No information available regarding whether the tool is updated or when the data/tool was prepared.
		Medium - The tool does not appear to incorporate updates, but provides information regarding the date when the tool was developed.
		High - New information is incorporated into the tool.
Discussion on funding sources	Information on funding sources can help the user understand the scope of the information provided, the potential for updates, and any potential conflicts of interest. It ensures that the tool's background is presented transparently.	Low - No information available
		Medium - Information available through supporting documents but not within the tool
		High - Information available within the tool

Evaluation of the tool through survey, modeling or contingent valuation method	Eliciting feedback is important for resolving any problems that users are having and provides information for improving the tool in the future. This also provides a way of understanding if the tool is providing a value in terms of decision support.	Low - No evaluation process available
		Medium - Option to give feedback only
		High - Evaluation through survey is available within the tool

3.2.1 Problem Identification and Decision Making Context

The primary focus on the development of climate services was to improve decision making in specific contexts. This involves some assumptions about which specific decisions can be improved with the climate data presented. At the same time, decision needs to be taken considering the spatial and temporal variability of climatic information, exposure to the variability, capacity to make decision under given climatic and non-climatic conditions, intended user groups. Identification of these information benefits the application of the information to the targeted user groups. Hence, this evaluation criteria is divided into three evaluation metrics Identification of decision making context evaluates whether the tool provides a discussion of the types of decisions where use of the tool would be appropriate or inappropriate. Discussion of the role of climate information in decision making evaluates whether the tool discusses how climate information could specifically be used to inform the decision. Finally, discussion of non-climatic factors evaluates whether related, non-climatic information (for instance, population projections or socio-economic data) is presented within the tool.

3.2.2 Characteristics, Tailoring and Communication of Relevant Information

The success and benefits of a climate service is dependent on the quality of the climate information it provides and the degree to which the intended user groups, that includes both technical and non-technical users and general people as well, can understand and use that information. Information on the reliability of the climatic information in any tool needs to be provided with proper discussion of the climate models used to derive the data if future projection information provided and observed data sources if hindcast information is provided, along with the intrinsic uncertainty and unpredictability in the climate system. At the same time, the information needs to be tailored to

meet the users' need in terms of preparing for response strategies, cultural traits, and specific situations. Hence, it needs to be understandable and accessible to nonexperts users along with the expert user groups. So, the characteristics, tailoring and communication of relevant information criteria is sub-divided into two metrics for the evaluation climate services: uncertainty of the data presented and accessibility of information. Uncertainty of the data presented evaluates how well the tools are providing information on uncertainty associated with the climate model information used to develop the tool. Accessibility of information evaluates whether the tools provide adequate explanation, tutorials and examples to make it easy to understand to its intended user groups.

3.2.3 Governance, Process and Structure of the Service

The success and benefits of the climate services depends on methods used in the development and delivery of climate services, including the institutional and administrative mechanisms, projects, and financial resources or funding sources. Transparency regarding this development process is one of the important design elements to determine the effectiveness of the tool or service. It is also important to maintain effective communication, transparency, and flexibility between service provider and user groups. Climate services developed under a continuous interaction between users and providers are usually considered more effective than those that do not have information on sustainability or continuity. At the same time, an efficient climate service engages with day to day research and incorporates updated information into the information they provide to its user group. Hence, the governance, process and structure of the service evaluation criteria is sub-divided into three metrics: discussion on the development process, sustainability/ ongoing process, and discussion of funding sources. Discussion on the development process aims to evaluate how well the tools are providing information on the organizations and processes used to design and create the tool, which is very important to make the tool's background more transparent. Sustainability/

ongoing process evaluates whether the tools are updated on a regular basis, or if information is provided about when the data were last updated. Discussion on funding sources assesses whether information is provided and easily viewed on the organizations and programs who provided funding for the tool's development. This is important to understand the scope of the information provided with potential of updated information being available in the future.

3.2.4 Value of the Service Provided

An effective climate services tool should provide an economic and/or social value to its users. Valuation information needs to be identified for specific context in order to avoid the devaluation of the impactful climate services that are targeted to low-income users which can be dismissed as of low value services. There are several ways to evaluate the value of the climate services in different decision systems and decision context. Evaluation of the tool can be made through survey, modeling or contingent valuation method. To confirm that the tool is providing a value to the intended user group, these methods must be available or incorporated into the tool. Thus, this metric evaluates whether or not the tool includes a mechanism (such as a survey or feedback form) to evaluate the value of the service to users and solicit feedback for further improvement.

3.3 Selection of Clearing Houses

Clearing houses are compilations of climate services tools that have been developed to provide general information about different climate services tools and websites so that various user groups can find tools that may be helpful to them. With a view to identify potential climate services tools, four clearing houses were selected initially based on literature review, the developing organization, and the size and comprehensiveness of the clearinghouse. The developing organization played an important role here as this information is useful to determine the effectiveness of the tool as well.

Two of the clearinghouses (Digital Coast and the US Climate Resilience Toolkit) were developed by federal organizations. The climate adaptation knowledge exchange (CAKE) was created by the nonprofit organization EcoAdapt, but is one of the largest clearing houses of its kind and includes several federal partners. The Climate Toolbox was developed by academic research groups in partnership with the USDA and the NOAA RISA program. We also chose these clearinghouses because they include a large and diverse grouping of tools. Figure 3.2 shows a methodological framework of how the climate services tools were selected for this study including a list of the four clearing houses that were selected.

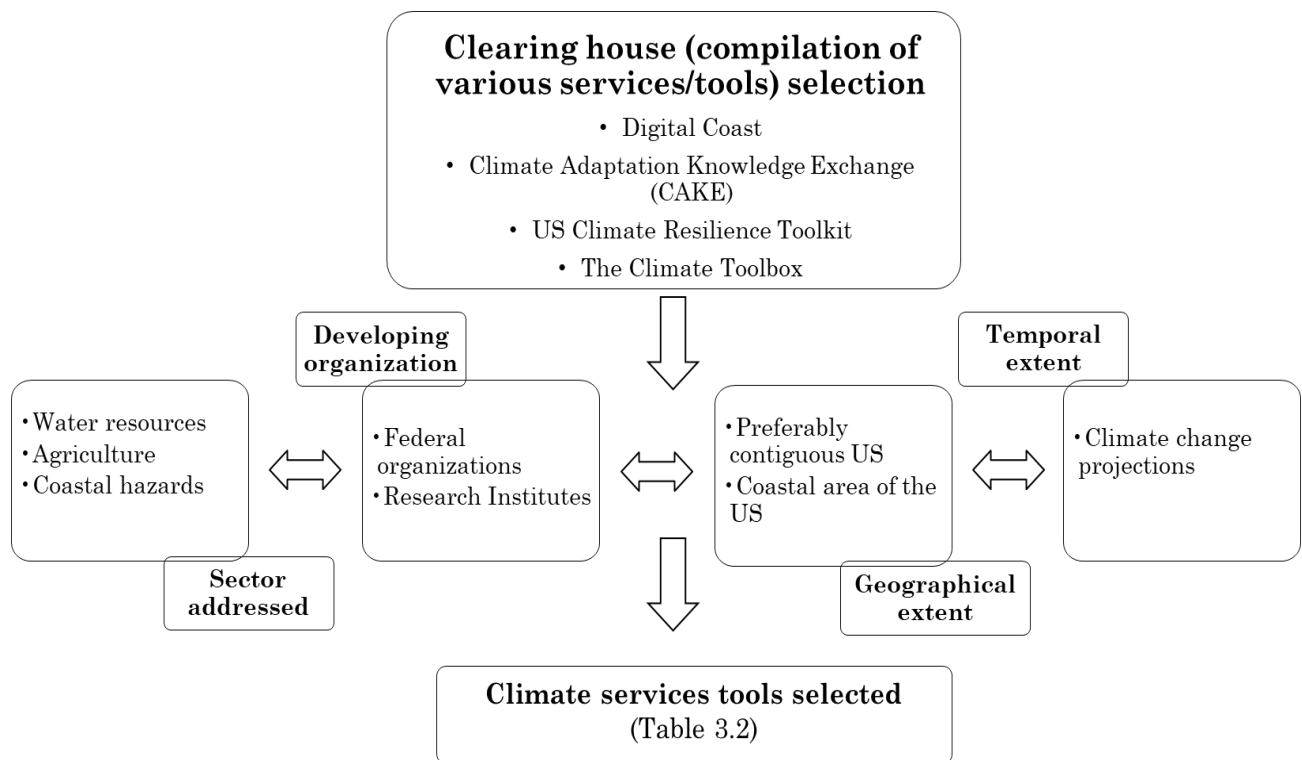


Figure 3.2: Methodological framework showing the selection of the climate services tools for the study

3.4 Selection of Tools

After initial selection of the clearing houses, four criteria were set for the selection of the climate services tools. These criteria are: sector addressed, developing organization, geographical extent, and temporal extent. For this study, the selected tools addressed the water resources, agriculture, and coastal hazards. In terms of developing organizations, the primary focus for this study was on the tools developed by federal organizations followed by research institutes. This study includes tools that cover either the entire United States or coastal regions of the United States, rather than a regional or local-scale tools. For the temporal period, the selected climate services tools provide long term climate projection information rather than historical data or short-term forecasts as this study aimed at evaluation of the tools for future climate change adaptation. List of the climate services tools selected for this study under these four criteria is given in Table 3.2.

3.5 Selection of Case Study Tools for Detail Study

After evaluation of the selected 19 tools, four tools were selected for detailed study and discussion. This detailed study gave more thorough insight of the effectiveness of the tools under the proposed evaluation design elements. Selection of the tools having relatively high, medium and lower rankings in the evaluation gave perceptions about the relative strengths and weakness of the tools. It helps understanding how these tools can be more effective in the decision making context under changing climate.

Table 3.2: List of the climate service tools selected for the study

Name of Tool	Web Address	Developing Organization	Regional Extent	Temporal Extent	Sector Addressed
Climate Explorer 3.0	https://crt-climate-explorer.nemac.org	NOAA	Contiguous US	1950 - 2013, projection for 2100	Temperature, precipitation, and related variables; high-tide flooding
Sea Level Rise Viewer	https://coast.noaa.gov/slr/	NOAA	Coastal area of the US including US territories (except Alaska)	It says projected information available in supporting document, but no information found	Sea level rise and coastal vulnerability
Surging Seas Risk Finder	https://riskfinder.climatecentral.org/	Climate Central	Coastal US	Both historical and future projection available	Coastal risk due to sea level rise
Climate Mapper	https://climatetoolbox.org/tool/Climate-Mapper	NW Climate Toolbox	Variable within the US	Both historical and future projection available	Climate, agriculture, hydrology, fire hazard
Future Crop Suitability	https://climatetoolbox.org/tool/Future-Crop-Suitability	NW Climate Toolbox	Variable within the US	Both historical (1971) and future projection (up to 2069) available	Crop suitability
Future Climate Dashboard	https://climatetoolbox.org/tool/Future-Climate-Dashboard	NW Climate Toolbox	Variable within the US	Both historical (1971-2000) and future projection	Temperature, precipitation

				(up to 2099) available	
Future Time Series	https://climatetoolbox.org/tool/future-time-series	NW Climate Toolbox	Contiguous US	Both historical (1950) and future projection (up to 2099) available	Climate
EnviroAtlas	https://enviroatlas.epa.gov/enviroatlas/interactivemap/	US EPA	Contiguous US; additionally, demographic data at the community level is available for some selected areas	Both historical and future projection available up to 2099 for different climate scenarios	Ecosystems
Climate Resilience Evaluation and Awareness Tool (CREAT) Climate Scenarios Projection Map	https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=3805293158d54846a29f750d63c6890e	US EPA	Contiguous US and Alaska, Hawaii, Puerto Rico	2035, 2060	Drinking water, wastewater and stormwater
Climate Inspector	https://gisclimatechange.ucar.edu/inspector	NCAR Community Climate System Model (CCSM4)	Global data	Up to 2090	Climatic information

Tribal Climate Tool	https://climatetoolbox.org/tool/Future-Tribal-Climate	Climate Impacts Group at the University of Washington and University of Idaho	Future climate projections for Pacific Northwest and Great Basin Tribes	Up to 2099	Climatic information
National Climate Change Viewer (NCCV)	https://www2.usgs.gov/landresources/lcs/nccv/viewer.asp	USGS	Contiguous US	Projection information available up to 2074	Climatic information
Climate Hydrology Assessment Tool	http://corpsmapu.usace.army.mil/cm_apex/f?p=313:2:0::NO	USACE	Contiguous US	Both historical (1950) and future projection (up to 2099) available	Only flow information
Sea-Level Change Curve Calculator (Version 2019.21)	http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html	USACE	Contiguous US and Alaska, Hawaii	Historic and projection information available	Sea level change calculator
Climate Wizard Custom Extreme	http://climatewizard.ciat.cgiar.org/index1.html	Collaborative project with World Bank group	Global data	Historic and projection information available	Climatic information
Locating and Selecting Scenarios Online	https://lasso.epa.gov	US EPA	Contiguous US	Historic and projection information available	Climatic information

Global Change Impacts & Adaptation- 20 Watersheds	https://20watersheds.epa.gov	US EPA	Contiguous US	Historic (from 1971) and projection (up to 2070) information available	Watershed simulation
Partnership for Resilience and Preparedness Data	https://www.prepdata.org	public-private collaborative project	Contiguous US and some global data available	Historic and projection information available	Different components of ecosystem services
Water Supply Stress Index (WaSSI)	https://web.wassiweb.fs.usda.gov	USDA	Contiguous US	Future projection information available	Different hydrologic information
Aqueduct Water Risk Atlas	wri.org/applications/aqueduct/water-risk-atlas	World Resources Institute (WRI)	Global	Baseline and projected (2020, 2030, 2040) information	Water resources

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the evaluation of the 19 decision support tools selected by following the methodology discussed in chapter three. A detailed case study evaluation is also discussed for four selected tools.

4.2 Evaluation of the Tools

The overall performance of the tools is shown in Figure 4.1 as stacked bar chart whereas the results of the evaluation work are shown in Table 4.1. Tools were evaluated based on the four design elements for evaluation proposed by Vaughan and Dessai (2014). This figure shows the number of tools that achieved low, medium, and high scores for each of the nine evaluation criteria. In terms of problem identification and decision making context most of the tools performed in the low (about 42 percent) and medium (47 percent) category. Only two of the tools have specific decision making context identified under certain problem for changing climate. Surging Seas Risk Finder and Future Crop Suitability have mentioned specific decision making context whereas Surging Seas Risk Finder is suitable for future sea level rise and associated flooding risk and Future Crop Suitability tool is useful for making decision in agricultural production in future climatic

conditions. Most of the tools have very limited discussion on how the information in the tool can be used for any specific situation, or have no discussion at all.

The first design element proposed by Vaughan and Dessai (2014) is problem identification and decision-making context. This study characterized this element using three evaluation criteria: identification of the decision-making context; discussion of the role of climate information in decision-making; and discussion of non-climatic factors.

Although the role of climate services is based on the assumptions about how the climate information can be used in decision making, the evaluated tools hardly have detail information on how the provided information can be used or what is the role of climatic information in different context. Only “Future Crop Suitability” provides information of how the climate information could help or influence in decision making related to climate change risk and adaptation. Other than this tool, remaining tools either provide information on climatic variables only without mentioning how they will impact in decision making or they provide no information at all.

Non-climatic factors, including population, housing and infrastructure, livelihoods, etc. are very important for proper risk assessment and decision making under climate change condition. However, the majority of the tools (about 68 percent) evaluated did not have any information on non-climatic factors. On contrary to that, five of the tools (Sea Level Rise Viewer, Surging Seas Risk Finder, EnviroAtlas, Global Change Impacts & Adaptation- 20 Watersheds and Partnership for Resilience and Preparedness Data) provided information of some non-climatic variables which are helpful in determining future risk whereas only Water Supply Stress Index (WaSSI) presented information on population only in addition to the climate variables.

The second design element of the evaluation framework proposed by Vaughan and Dessai (2014) is characteristics, tailoring and communication of relevant information which is classified into two evaluation metrics for this study. These are: uncertainty of the data presented and accessibility of information.

Evaluated tools showed mixed categorized performance in characteristics, tailoring and communication of relevant information criteria. Nine tools provided limited uncertainty information while remaining ten tools had information on detailed uncertainty condition. These uncertainty conditions include quantitative information on uncertainty (such as ranges, multiple (more than two) projections, or probabilities). These tools provided uncertainty information mostly in terms of RCP (Representative Concentration Pathway) scenarios. In most of the cases tools have considered RCP 4.5 for lower emission scenario and RCP 8.5 for higher emission scenario. In addition to the uncertainty information, tools showed better performance in presenting information and communicating effectively with the target audience. Among the evaluated tools, accessibility and interpretability information is comparatively easier to find, with 63 percent of tools scoring high and 37 percent scoring medium, often using example tutorials that are easy to find and understand even for non-expert users.

The third design element of the evaluation framework proposed by Vaughan and Dessai (2014) is governance, process and structure of the service. This element is further divided into three evaluation metrics for the purpose of evaluation of the tools in this study. These are: discussion on development process, sustainability/ ongoing process and discussion on funding sources.

Table 4.1: Evaluation of the tools for each of the nine evaluation criteria

Name of Tool	Problem identification and decision making context	Discussion of the role of climate information in decision making	Discussion of non-climatic factors	Uncertainty of the data presented	Accessibility of information	Discussion on development process	Sustainability/ ongoing process	Discussion on funding sources	Evaluation/ Feedback
Climate Explorer 3.0	Medium	Medium	Low	Medium	High	High	High	High	High
Sea Level Rise Viewer	Medium	Medium	High	Medium	High	Medium	High	Medium	Medium
Surging Seas Risk Finder	High	Medium	High	High	High	Medium	Medium	High	Medium
Climate Mapper	Low	Low	Low	Medium	High	High	Medium	High	Medium
Future Crop Suitability	High	High	Low	Medium	High	High	Medium	High	Medium
Future Climate Dashboard	Low	Low	Low	Medium	High	High	Medium	High	Medium
Future Time Series	Low	Low	Low	Medium	High	High	Medium	High	Medium

EnviroAtlas	Medium	Medium	High	High	High	High	Medium	Medium	Medium
Climate Resilience Evaluation and Awareness Tool (CREAT) Climate Scenarios Projection Map	Medium	Low	Low	High	High	High	Medium	Medium	Medium
Climate Inspector	Low	Low	Low	High	Medium	Medium	Medium	Medium	Medium
Tribal Climate Tool	Low	Low	Low	Medium	High	High	Low	High	Low
National Climate Change Viewer (NCCV)	Medium	Low	Low	High	High	High	High	Medium	Low
Climate Hydrology Assessment Tool	Medium	Medium	Low	High	Medium	Medium	Medium	Medium	Low
Sea-Level Change Curve Calculator	Medium	Medium	Low	High	Medium	Medium	High	Medium	Low

(Version 2019.21)									
Climate Wizard Custom Extreme	Low	Low	Low	High	Medium	Medium	Low	Medium	Low
Locating and Selecting Scenarios Online									
Global Change Impacts & Adaptation - 20 Watersheds	Low	Low	High	Medium	Medium	Medium	Medium	Medium	Medium
Partnership for Resilience and Preparedness Data	Medium	Medium	High	Medium	Medium	Medium	Medium	Medium	Medium
Water Supply Stress Index (WaSSI)	Low	Low	Medium	High	High	Medium	High	Medium	Medium
Aqueduct Water Risk Atlas	Medium	Low	Low	High	Medium	Medium	High	High	Medium

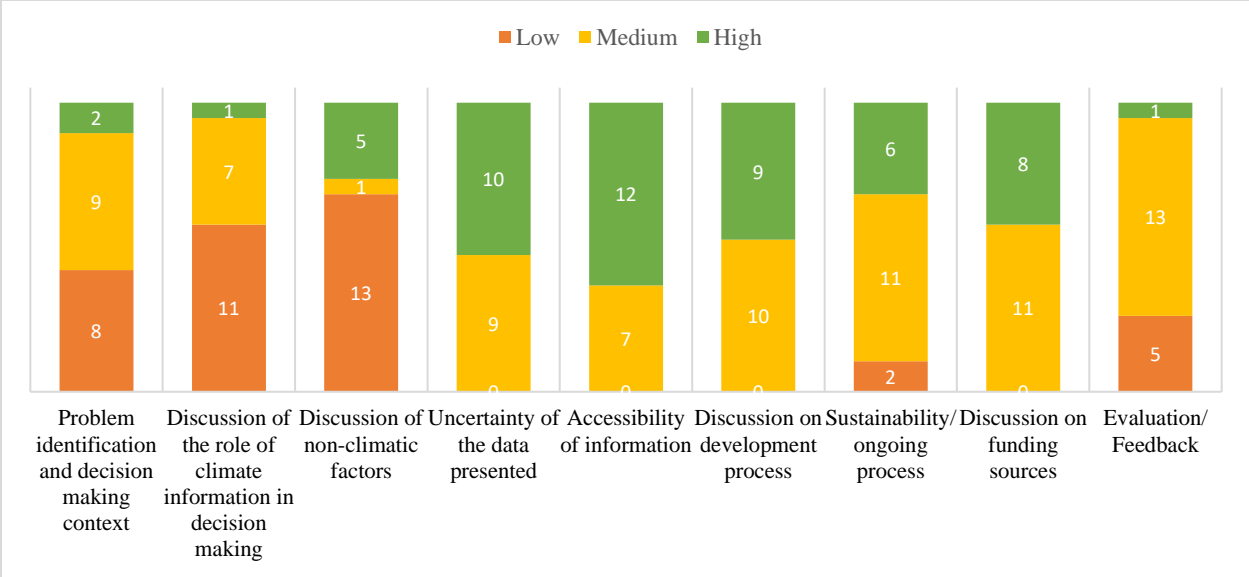


Figure 4.1: Stacked bar chart showing number of low, medium and high scores for each of the nine evaluation criteria

Governance, process and structure of the service is necessary to understand the background and transparency of the tools. Nine tools fell into high category in discussion of development process, while the remaining ten tools fell into medium category. All of them had information on development process either within the tool or in the supporting document. Tools provided information on the development of the tools, information used for tool’s development and which dataset were used etc. If the information is not available within the tool then it was relatively easier to find as it was linked within the tool. In terms of sustainability/ongoing process, most of the tools (about 58 percent) provided information regarding the date when the tool was developed but they did not seem to incorporate updated information in their tools. However, two of the tools did not have any information on update process of the information provided or when the dataset was prepared. On contrary to that, six tools provided detail information about the updated dataset used for the target audience. Discussion on funding sources is another important criterion to be

evaluated for the efficiency of decision support tools. All the nineteen evaluated tools provided information on funding sources either within the tool or in the supporting document.

The fourth design element of the evaluation of the climate services is the socioeconomic value of the service. It implies that the climate service should have some sort of economic value to its users from individual to society level.

Evaluation of the tools through surveys or contingent valuation methods have been used to assess the value of different types of climate services tools in terms of decision making. Among the evaluated tools, only Climate Explorer 3.0 have a structured survey option for its users within the tool to understand the value of the service they provide. About 68 percent of the tools had option to provide feedback to the developers which could be used for upgradation/ modification of the services they provide. However, five tools did not have any evaluation option available for the user end.

4.3 Detail Evaluation of Case Study Tools

After evaluation of the selected 19 tools, 4 tools have been selected for detail evaluation. These tools were selected based on the score they received in different evaluation criteria and the sector for which they are providing information. Detail discussion of the evaluation metrics for these tools gave more insight of the effectiveness and relative strengths and weakness of the tools. The case study evaluation tools are: Surging Seas Risk Finder, Climate Explorer 3.0, Future Crop Suitability, and Water Supply Stress Index (WaSSI).

4.3.1 Case Study 1: Surging Seas Risk Finder

Overview of the tool

The aim of “Surging Seas Risk Finder” (link: <https://riskfinder.climatecentral.org/>) tool is to provide information regarding the risk of coastal flooding and sea level rise due to changing climate to various levels of interested audience, such as policy makers, federal and local level authorities, and general people. This interactive tool provides information on local sea level and flood risk projection and its possible impact on population and several other social and economic variables. This tool provides customized downloadable tables and factsheets for the area of interest. It provides customized map generation and download option for coastal areas of the US with various levels of sea level rise in 1-foot increments from 1-10 feet. The downloadable fact sheet also includes information on likelihood of floods for selected water level; future risk information for different elements of risk including population, buildings, land, and their social and economic values. However, the developer of this tool recommended that the map should not be used for site-specific decisions. Rather it should be used for broader area of analysis which will provide more robust information due to its coarser data resolution (5 meters).

Developing organization: Climate Central (a non-profit research and journalism organization)

Regional extent of the data presented: Coastal areas of the US

Temporal extent of the data presented: Both historical and future projection available up to 2100

Horizontal resolution: 5 Meters (~15 feet)

Base sea level elevation: Mean Higher High Water (MHHW)

Sector addressed: Coastal risk due to sea level rise

Target audience: The tool discussed about its target audience for this tool which includes decision makers, planners, and managers from federal, state and local levels from different agencies, as well as general people and journalists who are interested in analysis of coastal threats especially flooding aggravated by sea level rise and changing climate.

Problem identification and decision-making context: Medium

Some general information on preparation for flooding is linked into Climate Central's website. However, specific details of type of flooding or changing conditions, nor any specific decision-making context was identified within the tool. For example, it has information about different types of interventions for long-term preparation against flooding but does not specify which interventions are appropriate for different flooding conditions. The flood preparation interventions mentioned in this tool are primarily aimed at protection of residences or buildings, such as maintenance, secure property, emergency supply kit and emergency plan, raise wiring, use of anchor to secure objects, safety box, alternate power source, raise home, flood vent, and flood insurance.

Discussion of the role of climate information in decision making: Medium

This tool has various climatic information which are primarily associated with sea level rise. No information is available about which factors are contributing for sea level rise scenarios or which factor should be considered for decision making purpose. For example, multi-year flooding risk above 5ft depth is given in the tool and used to determine elements at risk, including population, buildings, infrastructure, contamination risk and land.

Discussion of non-climatic factors: High

Multiple types of non-climatic data are available in this tool, including population, ethnicity, income property values, and important community buildings. This allows the user to see the potential impacts of higher sea levels.

Uncertainty of the data presented: High

For projection information, different sea level rise models and scenarios are presented in this tool to reflect uncertainty about possible rates of sea level rise. Storm surge driven water levels and storm surge frequency were considered for understanding the influence of sea level rise on coastal flooding (Tebaldi, Strauss, & Zervas, 2012). Kopp et al. (2014) used different representative concentration pathways (RCPs) for projecting future sea level rise. The information that have been used in the development of Surging Seas Risk Finder tool for future projection of risk maps for the contiguous coastal United States have shown 90% probability for future projection of climate scenarios.

Accessibility of information: High

Multiple tutorials are available that explain different components of the tool for easy understanding. Additionally, different RCP scenarios are described as extreme carbon cut and moderate carbon cut, avoiding the use of common terminology (RCP) that can be confusing. On the other hand, sea level rise scenarios are described as extreme, fast rise, medium rise and slow rise which can be easily understand by general people without having much knowledge on climate models or emission scenarios.

Discussion on development process: Medium

Although the development process of this tool is available, this information is not clearly labeled within the tool. The user must look into FAQ section for this information.

Sustainability/ ongoing process: Medium

There is no information available about whether the tool is regularly updated with new information. But the data source and data layers used in the tool have some information regarding which datasets are being used for future projection information. For example, multi-year risk of flooding above 5ft for Richmond area uses the median local sea level projections based on the intermediate scenario from NOAA Technical Report NOS CO-OPS 083. The data source for demographic, economic, infrastructure and environmental variables are mainly federal sources, including NOAA, USGS, FEMA, DOT, DOE, DOI, EPA, FCC and the Census data. The information was updated most recently using data from July 2016.

Discussion on funding sources: High

Some foundations have provided funding support for the program on Sea Level Rise at the Climate Central. Detailed information about the funding sources is available within the tool. (<https://sealevel.climatecentral.org/about/funding>)

Evaluation of the tool through survey, modeling or contingent valuation method: Medium

This tool has an option to send feedback, comments, suggestions within the website and suggests that users do so. However, there is no specific survey option available to provide feedback. Additionally, this contact option is not very easy to find as it is not available within the tool's main page. (<https://sealevel.climatecentral.org/about/contact/>)

4.3.2 Case Study 2: Climate Explorer 3.0

Overview of the tool

The “Climate Explorer” (link: <https://crt-climate-explorer.nemac.org>) is a free, web-based mapping and graphing tool developed by the NOAA’s Climate Program Office. It provides climate data for every county in the contiguous United States. The latest version of the tool incorporated information for Alaska and it has plans to include Hawai’i and U.S. island territories in future. This interactive tool provides information on temperature, precipitation and high-tide flooding for past and future projected data. It also provides historical weather data. It has both map and chart format of data for easy visualization and comparison for historical and future data.

Developing organization: Climate Program Office, National Oceanic and Atmospheric Administration

Regional extent of the data presented: Contiguous US

Temporal extent of the data presented: Both historical and future projections available to 2100

Sector Addressed: Climate information

Target audience: The developer of this tool has some intended target audience although it has not mentioned explicitly within the tool. The information could potentially be useful for the decision makers, planners, and managers from federal, state and local levels from different agencies, and general people and journalists who are interested in understanding and analyzing the climate related hazards and build resilience against them.

Problem identification and decision-making context: Medium

Some general information on high tide flooding is available within the tool with some possible solution of this problem is mentioned in the Climate Central's website linked within the tool. However, the type of decision that could be taken under a specific situation is not identified in the tool. However, specific details of type of flooding or changing condition nor any specific decision-making context was identified within the tool.

Discussion of the role of climate information in decision making: Medium

This tool provides data on temperature, precipitation related variables and high tide flooding information. However, no information was available about which factors are need to be considered while making decision for future planning or which variable will be more or less important in deciding future risk. Some general considerations are discussed in the FAQ section about how the variables are important in different future scenario. For example, climate projections should be used cautiously as these are based on the assumptions about future emissions for both natural and anthropogenic sources; climate projections should not be considered for predicting the timing of specific meteorological events like storms, droughts, or El Niños.

Discussion of non-climatic factors: Low

No information is available about non-climatic variables in this tool.

Uncertainty of the data presented: Medium

For projection information, different sea level rise models and scenarios are presented in this tool to reflect uncertainty for future changing climate. Two possible future scenarios are considered in this tool for graphs and maps. One is a lower emission scenario (RCP 4.5) which implies humans

reduce and stabilize global emissions of heat-trapping gases; another is a higher emission scenario (RCP 8.5) which reflects continuous increase of emissions through the end of the 21st century.

Accessibility of information: High

This tool is easy to understand and find required information from user end. Information is clearly labeled which can be easily understood by general people without having much knowledge on climate models or emission scenarios. Basic information on emission scenarios is also provided within the tool.

Discussion on development process: High

The development process of this tool is available and described briefly in the FAQ section. Some additional information is also linked within the tool which the user can find for better understanding about the development process of the tool.

Sustainability/ ongoing process: High

Climate explorer is updated regularly based on the user feedback. They are incorporating new variables and related information in newer versions as well. Hence, in terms of sustainability/ ongoing process this tool is performing very well. It also provides information on the dataset used, emission scenarios considered for future projection which are clearly mentioned within the tool.

Discussion on funding sources: High

Development of the Climate Explorer was directed and overseen by a collaborative effort of an interagency team of federal climate model experts from the Environmental Protection Agency (EPA), NASA, NOAA, and the U.S. Geological Survey. This team was chaired by the U.S. Global Change Research Program.

Evaluation of the tool through survey, modeling or contingent valuation method: High

This tool has an option to send feedback, comments, suggestions within the tool which directs user to a structured survey option. The developers are continuously incorporating user feedbacks in the tool and they are releasing newer version regularly.

4.3.3 Case Study 3: Future Crop Suitability

Overview of the tool

The aim of the “Future Crop Suitability” (link: <https://climatetoolbox.org/tool/Future-Crop-Suitability>) tool is to provide information about the potential impact of climate change for growing different specialty of crops grown in the Western USA, including apples, blueberries, and cherries. It provides information for most of the Western USA. This tool includes crop suitability information, crop phenology analysis and irrigation water demand for historical and future scenarios. Future projection information is available until 2069. This interactive tool provides downloadable graphs and maps for user reference.

Developing organization: Northwest Climate Toolbox

Regional extent of the data presented: Variable within the US, mostly the western USA

Temporal extent of the data presented: Both historical and future projection available up to 2069

Spatial resolution: 1/24-deg (4-km, 2.5-mile)

Sector Addressed: Agriculture

Target audience: The intended user of this tool, as mentioned in the tool, is a farmer or agricultural professional who has sufficient science background to understand the limitations of the information provided within the tool.

Problem identification and decision-making context: High

This tool performed very well in terms of problem identification and decision making. It provides information on three types of analysis: suitability, phenology and irrigation. Under each of the criteria, it provides information for future farming condition and growth suitability considering different changing climate scenario.

Discussion of the role of climate information in decision making: High

This tool has various climatic information under crop suitability of analysis. It considers higher emission (RCP 8.5) and lower emission (RCP 4.5) scenarios for future projection. It provides information of potential crop growth under different climatic conditions.

Discussion of non-climatic factors: Low

This tool does not consider any non-climatic factors for assessment of future crop suitability.

Uncertainty of the data presented: Medium

Future Crop Suitability considers higher emission (RCP 8.5) and lower emission (RCP 4.5) scenarios for future projection.

Accessibility of information: High

Examples and tutorials are available that explain different components of the tool for easy understanding. Virtual tour describing different components of the tool is very user friendly and easy to understand.

Discussion on development process: High

The development process of this tool is discussed within the documentation section of the tool and is easy to find.

Sustainability/ ongoing process: Medium

There is no information available about whether the tool is regularly updated with new information. But the data source and data layers used in the tool have some information regarding which datasets are being used for future projection information although this information is not directly available within the tool rather it is linked to external website in the documentation section.

Discussion on funding sources: High

Information about the funding source is available within the tool. Climate Hub and Climate Impacts Research Consortium (a NOAA RISA) funded the development of this tool.

Evaluation of the tool through survey, modeling or contingent valuation method: Medium

This tool has an option to send feedback, comments, suggestions within the Climate Toolbox website and suggests that users do so. But there is no structured survey option available to provide feedback from user end.

4.3.4: Case Study 4: Water Supply Stress Index (WaSSI)

Overview of the tool

The aim of “Water Supply Stress Index (WaSSI)” (link: <https://web.wassiweb.fs.usda.gov>) tool is to provide information regarding the impact of land use change, climate change, and water withdrawals on river flows, water supply stress, and ecosystem productivity. This tool is primarily categorized as ecosystem services model as mentioned in the user guide of the tool. It provides information for the contiguous United States, Mexico, Rwanda, and Burundi for historical and future projections. Different layers have different years of historical and future information.

Developing organization: United States Department of Agriculture

Regional extent of the data presented: Contiguous USA, Mexico, Rwanda, and Burundi

Temporal extent of the data presented: Both historical and future projection available

Sector Addressed: Land use change, watershed hydrology under changing climate and ecosystem productivity

Target audience: The intended target audience of this tool, as mentioned in the tool, are the decision makers, planners, and managers from federal, state and local levels from different agencies, and general people although some sort of scientific knowledge is expected to understand the outputs of this tool.

Problem identification and decision-making context: Low

This tool provides information on multiple variables related to watershed hydrology, land use land cover change, water use etc. but they do not identify any specific situation or decision for any

given condition. Hence, this tool performed low in problem identification and decision-making context.

Discussion of the role of climate information in decision making: Low

This tool does not specify the role of climatic variable in future scenario. Not do they specify any decision making condition. Hence it was categorized low in terms of discussion of the role of climate information in decision making.

Discussion of non-climatic factors: Medium

The WaSSI tool provides population projections for the geographical area it covers. Other than population information, it provides climatic variable information for evaluating trade-offs among different management strategies for selected ecosystem services.

Uncertainty of the data presented: High

This tool incorporated multiple climate model projections for future simulation. Users have flexibility to select required climate scenario based on the intended use of the simulation result.

Accessibility of information: High

A user guide (available in both English and Spanish) provides detailed information on how to access information within the tool and a step-by-step simulation guide for user reference. Although this guide is not available within the tool, it is directly linked with the homepage of the tool and easy to find.

Discussion on development process: Medium

The development information is mentioned briefly in the user guide of the tool. The model algorithms were developed by the Eastern Forest Environmental Threat Assessment Center. The Rwanda part of the model was developed through the collaboration with the Rwanda Agricultural Board and Wildlife Conservation Society.

Sustainability/ ongoing process: High

The tool incorporated updates on different variables including water balance and flow routing algorithms, future climate scenarios, land and water conditions. It also incorporates updates by adding 20 general circulation models from the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report. All these information are available in the user guide for the tool.

Discussion on funding sources: Medium

The WaSSI tool received funding support from the Eastern Forest Environmental Threat Assessment Center and the USDA Forest Service International Program. The WaSSIweb server was developed with the funding support provided by the Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University; this was a part of the National Science Foundation grant.

Evaluation of the tool through survey, modeling or contingent valuation method: Medium

This tool has an option to send feedback on WaSSI content, user-friendliness, and/or results which is available within the tool. There is no structured survey option available to provide feedback from user end.

4.4 Limitations of the Study

This study evaluated a total of 19 publicly available decision support tools which focused on water resources, agriculture and coastal hazards in the United States. This study looked at each tool in more detail than previous evaluations, but this level of detail required a reduction in the total number of tools included. There are many other tools that provide information on food security, health, energy, human security etc. Evaluating those tools is beyond the scope of this study. Many other tools provide information on local scale climate variability which could not be included in this study due to time constraint.

4.5 Recommendations for Future Study

Based on the experience and learnings from the present study, few recommendations for the future work are provided below.

- This study primarily considered climate services tools that provided information for Contiguous US or the coastal US. However, there are many other tools that have information on specific region or specific community. Similar study can be carried out for location specific tools.
- In this study, tools have been considered for evaluation that addressed water resources, agriculture and coastal hazards. Additional tools can be considered for evaluation that addressed sectors different than these three.
- Some climate services tools provide historical information only. Those tools can be evaluated in future study as historical information is also important for better understanding

of the overall climate condition for any location and make proper adaptation strategy for future climate change.

- Climate service providers need to follow the development and evaluation guidelines and criteria to be more effective in providing information to its user groups. At the same time, user of these services also needs to review if there is any evaluation for any specific tool is available prior using that information or look critically if the tool is maintaining climate services guidelines or not.

CHAPTER FIVE

SUMMARY AND CONCLUSION

This study evaluated how well the 19 climate services performed in terms of problem identification and decision making context, providing tailored information to its user group, maintaining transparency in the governance and development the services, and assessment of its socio-economic values.

The evaluation results reflect that the tools perform well in the design elements “characteristics, tailoring, and communication of the climate information” and “governance, process, and structure of the climate service”. Most of the tools have provided well-tailored information to its users that can be used for proper decision making due to changing climate. They provided examples, tutorials on how to use the tool which make them easy to understand to the non-expert user as well. Most of the tools provided sufficient information on the development process, funding sources of the tool within the tool or have information in supporting documents which are relatively easy to find within the tool. Additionally, most of the tools incorporated updated climatic information in the tool, or they provide information regarding when the tool was updated or which information is being used in the tool.

In terms of “problem identification and the decision-making context”, the evaluated tools performed average as most of the tools did not provide information on specific decision making context. The evaluated tools have information on various climate related information, such as

temperature and precipitation projections, but they did not identify how the information should be used for any specific problem or any specific situation for making adaptation or mitigation strategies. At the same time, most of tools provided information on climatic variables only, whereas non-climatic information is equally important to understand future risk and vulnerability due to climate change.

The success of the climate services tools is also related to how well they incorporate user feedback. However, the majority of the evaluated tools have option to give feedback from user end, with only one tool having a structured survey to provide feedback. This evaluation or feedback is important for the climate services to be success and acceptable to the users from different income groups.

The case studies showed detail evaluation of four of the climate services tools used in this study which provide an explanation of why the any tool get a specific score in an evaluation criterion. This is very useful in understanding how the tools are performing based on the evaluation metrics.

Based on the four design elements of the evaluation framework and nine evaluation metrics, it can be said that the design elements and evaluation metrics discussed different aspects of climate services which are needed for the services to be effective in providing information to the user; for the users also useful to understand how the service provider is doing in terms of giving information maintaining transparency, integrity, ethics etc.

Climate services provides various climate and non-climate information to its users with both historical and future projected information. This evaluation works gave an insight on how the tools are doing based on the framework proposed by Vaughan and Dessai (2014). Ultimately, this

evaluation can be used to support better decision making that uses existing climate services and improved development of climate services that can meet adaptation decision needs.

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