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Development of an evolutionary game-theoretical model for trustworthy multi-channel information gathering and dissemination system framework among fisheries stakeholders

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DEVELOPMENT OF AN EVOLUTIONARY GAME-THEORETICAL MODEL FOR TRUSTWORTHY MULTI-CHANNEL INFORMATION GATHERING AND DISSEMINATION SYSTEM FRAMEWORK AMONG FISHERIES STAKEHOLDERS

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Information and Communication Science and Engineering of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Fisheries and its value added products contributes substantially in the socio-economic of developing countries including Tanzania. Researches shows that fisheries sector contributes 4.7% and 2.4% of the Gross Domestic Product (GDP) of Kenya and Tanzania respectively. Despite its huge contribution to socio-economic of the country, the Tanzania fisheries stakeholders remain challenged with limited access of fisheries information, knowledge, skills and new technologies. This challenges hinders the fisheries sector development and reduces income to stakeholders as well as the Government. This study investigated the fisheries information collecting and distribution among fisheries stakeholders in Mara and Mwanza regions of Tanzania. The study examined the channels owned and used by fisheries stakeholders to gather and disseminate fisheries information. Data were collected by administering a survey in four (4) districts purposively selected from the two regions and 400 respondents randomly selected was involved. The data were analyzed using python panda library and presented using bar and pie charts. Using the collected data, channel dissemination effectiveness probability of the six channels (short Message services, Cellular phone call, Television, Radio, mobile application, and Website) were calculated and comprehensive analysis performed using python plotly library. Furthermore, the study developed a multi-channel fisheries information management system architectural framework and a participation-reputation game based incentive mechanism namely EPRIGM to encourage the fisheries stakeholders donate truthful information and feedback. We modeled and simulated the dynamics of stakeholder’s strategy selection using replicator dynamic concept and derive the evolutionary stable strategies for the stakeholders. Results revealed that there is no single channel application that fits all stakeholders and that EPRIGM ensures truthful and honest stakeholders participation in gathering and disseminating fisheries information. In this study, we considered only seven parameters, namely channel coverage, listening ratio, watching ratio, channel access, average access time, information usefulness, and information sharing, in calculating channel effectiveness probability. Lastly, the empirical results of EPRIGM simulation revealed that all information users and information providers will choose honest strategy to capitalize on their earnings. We do recommend further studies to consider more factors like channel carrying capacity and channel costs in calculating channel effectiveness probability and consider application of EPRIGM in other domain of activities.

DECLARATION

I, Sadiki Lameck Kusyama do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor presented for similar degree award in any other institution.

Sadiki Lameck Kusyama 27/07/2022

Name and Signature of the Candidate Date

The above declaration is confirmed by:

Pof. Michael Kisangiri

28-07-2022

Name and signature of Supervisor 1 Date

Dr. Dina Machuve

27/07/2022

Name and Signature of Supervisor 2 Date

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CERTIFICATION

The undersigned here, certify that, they have read and hereby recommend for acceptance by the Senate of the Nelson Mandela African Institution of Science and Technology, a dissertation titled *"Development of an evolutionary game-theoretical model for trustworthy multi-channel information gathering and dissemination system framework among fisheries stakeholders"* in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Information and Communication Science and Engineering of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

$r_{j,t}$	Providers Pj weighted accumulated number of useful information or truthful feedback uploaded at time t
$q_{i,t}$	Users Pi weighted accumulated historical system logs at time *t*
$q_{j,t}$	Providers Pj weighted accumulated historical system logs at time *t*
$r_{i,t}$	Users Pi weighted accumulated number of useful information or truthful feedback uploaded at time *t*
ACM	Association for Computing Machines
ACP	African Caribbean and Pacific
AfDB	The African Development Bank
AMSDP	Agricultural Market Systems Development Program
CLF	Converged Licensing Framework
CR	Channel Coverage ratio
DSRM	Design Science Research Methodology
EFMIS-Ke	Enhanced Fish Market Information Services Kenya
e-GA	e-Government Authority
EPRIGM	Evolutionary Participation-Reputation Incentive Game Model
ESSs	evolutionary stable strategies
FAO	Food and Agriculture Organization of the United Nations
FIC	Fisheries Information Centre
GDP	Gross Domestic Product
GDP	Gross Domestic Product
ICT	Information Communication Technology
Ir	Incentive rate
IVR	Interactive Voice Response
KACE	Kenya Agricultural Commodity Exchange
KACE	Kenya Agricultural Commodity Exchange
LVFO	Lake Victoria Fisheries Organization
MLFD	Ministry of Livestock and Fisheries Development
MRC	Market Resource Centre
MRCs	markets through a network of franchised market resource centers
NARA	The National Aquatic Resources Research and Development Agency
NFP	National Fisheries Policy

ODK	Open Data Kit
OINZ-AD	truthful online incentive non-zero arrival-departure
PDA	Portable Digital Accessory
PDA	Portable Digital Accessories
Pi, Pj	Information providers and information users respectively
Pi, Pj	Information providers and information users respectively
Pr	Penalty rate
Ri,t	Users Pi reputation Score at time t
Rj,t	Providers Pj reputation Score at time t
SMS	Short Message Services
SMS	(short Message services
SP	service providers
TBA	threshold-based auction
TOIM	honest online incentive
Ui,t (x,y)	The expected Utility for user Pi at time t when information provider takes action x and information user takes action y
UNCTAD	United Nations Conference on Trade and Development
URT	United Republic of Tanzania
USAID	The United States Agency for International Development
USSD	Unstructured Supplementary Service Data
VCA	Value Chain Analysis
WTO	World Trade Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

1.1.1 Overview of Fish Industry in Developed Countries

Fisheries and its value-added trade account for 1% of global Gross Domestic Product (GDP), half it originating in developing countries (Mallalieu, 2015). The sector also inhabits a substantial contribution in the socio-economic growth of numerous countries (Phiri *et al.,* 2013; Njiru *et al.,* 2019; Aura *et al.,* 2019; Woodhead *et al.,* 2018). In 2016, over 40 million people were involved in fisheries subsector globally and about 90% were small-scale fisheries (Food and Agriculture Organization of the United Nations [FAO], 2018). Fish was testified to be the subsequent most exported agricultural product intra-regionally, after sugar (United Nations Conference on Trade and Development [UNCTAD], 2013) and World Trade Organization (WTO, 2014) mentioned cotton, coffee and fish to be among agricultural commodities with export prospective. Fisheries subsector subsidizes about 4.7% of GDP in Kenya (Mulatu *et al.,* 2018) and around 2.4% of GDP in Tanzania (United Republic of Tanzania [URT, 2016).

1.1.2 Fish Industry in Tanzania

Tanzania is among the developing countries with industrialization vision like Kenya, Uganda and Rwanda. The importance of fisheries resources in developing country with industrialization vision cannot be undermined. Tanzania is gifted with fisheries resources from marine, freshwater, riverine and wetland types. About 37% of Tanzania's area is made up of inland waters. Tanzania owns 51% of Lake Victoria, 41% of Lake Tanganyika, and 20% of Lake Nyasa (URT, 2016). There are also a number of rivers, including the Rufiji, Kilombero, Ruvu and Pangani, as well as a number of minor natural lakes, artificial lakes, or dams. The most productive freshwater fishery in Africa is Lake Victoria (Katunzi *et al.,* 2017). Lake Victoria supplied about 63% of all freshwater fish output in 2013, Lake Tanganyika contributed about 18%, and Lake Nyasa contributed about 3% (URT, 2016). In 2014, inland fisheries accounted for roughly 85% of national fish production, with Lake Victoria and Lake Tanganyika accounting for nearly 94% of total inland fish production (URT, 2016). Since the late 1990s, Lake Victoria has given the majority of the overall fishery contribution to the Tanzanian economy, providing an annual average of US$100 million for the central government (Lake Victoria Fisheries Organization [LVFO], 2015). Furthermore, in 2015, the

Fisheries sector employed roughly 183 800 people directly and about 4 000 000 people indirectly as boat builders, fish processors, net and engine repairers (URT, 2016).

Despite the importance of fisheries sector in industrial development, socio- economic development and employment provision, this sector is still facing various challenges including illegal fishing, inefficient resource management, high post-harvest losses and poor fishing gears (URT, 2015). Other challenges are inadequate extension services, uncompetitive market, geographical isolation, and over exploitation of resources. As a result, effective use of ICTs can increase fisheries stakeholders' access to information, knowledge, skills, and technology. According to FAO (2020), African fisheries and aquaculture data collection systems are not performing satisfactorily and are not providing all of the information needed to assess the appropriateness of fisheries and aquaculture policy and management decisions. Also are not useful for tracking the status of exploitation of fishery resources and the overall performance of existing fishery management measures.

1.1.3 Tanzania and Advancement and Application of Information and Communication Technology in Fish Industry

Information and communication technology (ICT), community, entrepreneurship and industry development all have a strong link. In the last two decades, developing countries have seen ICT improve the capacity of various communities such as farmers, educators, entrepreneurs, and industry. According to the Tanzania Investment Centre, Tanzania's government is expected to become a knowledge-based society, with a goal of having a comprehensively accessible broadband infrastructure in ICT (Information Communication Technology [TIC], 2017). Tanzania's government has made significant investments in ICT infrastructure development in order to realize this vision. The Converged Licensing Framework (CLF), the transition from analogue to digital television broadcasting, the establishment of a National ICT Broadband Backbone, the expansion of media transmission systems to rural communities, and monetary consideration through mobile money innovation are all examples of these.

However, the fisheries community has not benefited with this huge government investment in ICT infrastructure. Tanzania fisheries community remain facing various challenges including illegal fishing, inefficient resource management, high post-harvest losses, unfair and noncompetitive market, poor fishing gears, and over exploitation of resources (URT, 2016). The availability of ICT backbone has huge potential for providing appropriate knowledge, awareness, and skills to fisheries community and eradicate afforest mentioned challenges in the sector. Fisheries data is an obligatory instrument for achievable fisheries asset management and improvement. Nevertheless, collection, storing, handling and dissemination of fisheries data are inefficient (URT, 2015).

Quresh *et al.* (2014) affirmed that ICT has the capability of abolishing different fisheries difficulties and improve network advancement. The study by Mtega and Benard (2013) uncovered that good information raises basic leadership, improves proficiency and conveys an upper hand. Schubert *et al.* (2022), likewise detailed an absence of fishery information and its effect on society. In their study, they detailed that inaccessibility to data and information prevents fishers to improve their fisheries productivity activities. As indicated by Benard and Dulle (2017), accessibility of data and information among fishers lessens fish creation rate and the utilization of ICTs in recovering and sharing fisheries data and information is of incredible noticeable quality. The ICT is an enabler for the interchange of data and information on distinctive fishing practices among fishers and stakeholders that include experts (Kamau *et al.*, 2021).

In spite of the development and accessibility of ICT channels (Radio, TV, Mobile telephone, and web sites) as of late, the fisheries sub-sector remains the lowest in utilizing ICTs. The customary media (radio, Television, Telephone call) occasionally utilized in social affair and scattering fisheries information. Nevertheless, these customary methods for social event and scattering fisheries information are inefficient and expensive. The current methods of collection, analysis, storage and dissemination of fisheries and aquaculture data is costly and time consuming (Obiero *et al.*, 2019). Poor fisheries data collection, analysis, storage and dissemination schemes are caused by a lack of human and financial resources for data collecting, analysis, storage and dissemination (Obiero *et al.*, 2019). These persisting challenges resulted in poor quality information and limited the use of statistics in fisheries management and proper fisheries policy development. In light of these challenges, one potential trend over the last two decades has been the significant expansion of data and communication technologies (ICTs) reach and selection, particularly in remote country zones (Monga *et al.*, 2014; Nakasone *et al.*, 2014). The ICTs have the potential to extend fishers' get to open and private information, as well as interface buyers and venders, encourage rural information collection and make strides get to financial services.

1.1.4 Innovations in Fisheries Data Collection and Dissemination

Several innovations have been proposed by experts around the world to solve the issues of fisheries data collecting and dissemination. The ABALOBI effort, for example, was created in South Africa using open source software to track, trace, and collect data from small-scale fishermen (Petrik & Raemaekers, 2018). The Enhanced Fish Market Information Service Kenya (EFMIS-Ke) is a virtual marketplace program that aims to provide fishermen with market information and reduce poverty by increasing transparency in prices (Aura *et al.*, 2019). Hapi Fish is a mobile phone application developed in the Solomon Islands to provide fast and resourceful access to market and biological data (Mallalieu, 2015). Esoko, a Ghanaian ICT platform meant to make data gathering, market information, and payments easier for crop farmers, can also be adjusted for fishermen (Schalkwyk *et al.,* 2017).

However, most innovative solution proposed focused on horizontal value chain and left behind the vertical value chain (Mallalieu, 2015). Lacking the link between horizontal and vertical value chain caused fragmentation between various actors along the fisheries value chain (Petrik & Raemaekers, 2018). Furthermore, individual users frequently incur a cost when participating in such crowd nature systems. Users' resources usage, such as processing power, battery, airtime and internet bundles are examples of such expenses. On the other hand, the system may necessitate the input of some of a user's delicate private information, thus exposing the user's privacy. For example, fishermen can reveal their daily earnings by sharing their daily catch. Fishermen frequently share information about their locations by registering landing sites. As a result, without a reasonable incentive to offset the expenses of participation, people will be hesitant to practice such systems. The majority of current fisheries innovation systems rely on user input and lack appropriate incentive mechanisms.

1.2 Statement of the Problem

Ideally, fisheries stakeholders would be able to maximize their production and hence increase their income by being able to access valuable information (like market prices, fishing gears availability, best fishing practice etc.) timely. Currently, fisheries sector has limited link between horizontal and vertical value chain and hence limiting access and provision of valuable information among the sector stakeholders. Horizontal value chain is a typical model that depicts the transmission of harvested fish via a variety of stages of sale, value addition and consumption. Vertical value chain depicts stages of value addition in form of physical/instrumental, informational, processes/transactional, organizational and strategic. This has caused fragmentation among various actors in the fisheries value chain, poor participation of actors in timely data generation, limited accessibility of valuable information, low efficiency and effectiveness. Thus the fisheries stakeholders are unable to maximize their production as well as their income.

Operative fisheries development and management necessitates clear communication and coordination among all stakeholders. Tanzania's government currently has few means of communicating with fishers about best practices, rules, and fisheries management interventions. Anglers also have limited access to critical information like market prices and real-time weather data that could help them enhance their profession (URT, 2015).

Several innovation has been proposed by scholars worldwide to address fisheries data collection and dissemination challenges (Petrik & Raemaekers, 2018; Mallalieu, 2015; Schalkwyk *et al.,* 2017). However, most innovate solution proposed focused on horizontal value chain and left behind the vertical value chain (Mallalieu, 2015). Lacking the link between horizontal and vertical value chain caused fragmentation between various actors along the fisheries value chain (Petrik & Raemaekers, 2018). Furthermore, contemporary innovation platforms rely on user participation that is voluntary, lacking effective motivational incentives. According to Obiero *et al.* (2019), the primary elements to consider during the design and implementation of fisheries and aquaculture data collecting, analysis, and dissemination systems are accuracy, sustainability, relevance, timeliness, comparability, availability and accessibility of acquired data. As a result, without a reasonable incentive mechanism to offset the costs of participation, users will be hesitant to use such systems.

This research investigated how to enhance information collection, storage, processing and dissemination in fisheries subsector considering three challenges, lack of link between horizontal and vertical value chain, fragmentation among various actors along the value chain and lack of incentive mechanism. In particular, the study identified specific ICT tools accessible by various stakeholders, determined the effective channel probability of each ICT tools for each stakeholder groups employing comprehensive channel effective probability comparison. Finally, developed an evolutionary game-theoretical model for truthful worthy multi-channel information gathering and dissemination system framework among fisheries stakeholders in Mwanza and Mara regions in Tanzania.

1.3 Rationale of the Study

Fisheries and its value-added trade account for 1% of global Gross Domestic Product (GDP), half it originating in developing countries (Mallalieu, 2015). The sector also inhabits a substantial contribution in the socio-economic growth of numerous countries (Phiri *et al.,* 2013; Njiru *et al.,* 2019; Aura *et al.,* 2019; Woodhead *et al.,* 2018). Tanzania is among the developing countries with industrialization vision like Kenya, Uganda and Rwanda. Despite the importance of fisheries sector in industrial development, socio- economic development and employment provision, this sector is still facing various challenges including illegal fishing, inefficient resource management, high post-harvest losses and poor fishing gears (URT, 2015). Other challenges are inadequate extension services, uncompetitive market, geographical isolation, and over exploitation of resources. As a result, effective use of ICTs can increase fisheries stakeholders' access to information, knowledge, skills and technology.

Tanzania's government has made significant investments in ICT infrastructure development in order to realize this vision. The Converged Licensing Framework (CLF), the transition from analogue to digital television broadcasting, the establishment of a National ICT Broadband Backbone, the expansion of media transmission systems to rural communities, and monetary consideration through mobile money innovation are all examples of these. However, the fisheries community has not benefited with this huge government investment in ICT infrastructure. Tanzania fisheries community remain facing various challenges including illegal fishing, inefficient resource management, high post-harvest losses, unfair and noncompetitive market, poor fishing gears, and over exploitation of resources (URT, 2016). The availability of ICT backbone has huge potential for providing appropriate knowledge, awareness, and skills to fisheries community and eradicate afforest mentioned challenges in the sector. Fisheries data is an obligatory instrument for achievable fisheries asset management and improvement. Nevertheless, collection, storing, handling and dissemination of fisheries data are inefficient (URT, 2015). Therefore, the present study was aimed to develop an evolutionary game-theoretical model for truthful worthy multi-channel information gathering and dissemination system framework among fisheries stakeholders in Tanzania's Mwanza and Mara areas.

1.4 Research Objectives

1.4.1 General Objective

The major goal of this study was to develop an evolutionary game-theoretical model for truthful worthy multi-channel information gathering and dissemination system framework among fisheries stakeholders in Tanzania's Mwanza and Mara areas. We devised the following precise objectives in order to attain this goal:

1.4.2 Specific Objectives

(i) To assess the strength and weakness of the existing mechanism used to collect, disseminate fisheries information and motivate system users to participate honestly.

(ii) To design a multi-channel information collection and dissemination system Framework among fisheries stakeholders.

(iii) To design an incentive mechanism to motivate honesty and trustful use of fisheries information collection and dissemination system framework.

(iv) To code the designed incentive mechanism to motivate honesty and trustful use of fisheries information collection and dissemination system framework.

(v) To simulate the designed incentive Mechanism and analyze their effect on a multi-channel information collection and dissemination system Framework among fisheries stakeholders.

1.5 Research Questions

(i) What is the relevance of existing mechanism used by fisheries community to collect, disseminate fisheries information and motivate system users to participate honestly?

(ii) What are the parameters/factors suitable for consideration during the design of a multi-channel information collection and dissemination system Framework among fisheries stakeholders?

(iii) What are the parameters/factors suitable for consideration during the design of an incentive mechanism to motivate honesty and trustful use of fisheries information collection and dissemination system framework?

(iv) How would the designed incentive mechanism to motivate honesty and trustful use of fisheries information collection and dissemination system framework be coded for achieving best performance?

(v) What is the value added by the developed incentive mechanism for trustworthy multi-channel information collection and dissemination framework among fisheries stakeholders in Mwanza and Mara region?

1.6 Significance of the Research

Tanzania acknowledges the importance of using ICT in fisheries information collection and dissemination. In its Nation fisheries policy, the government has the mission to facilitate the transformation of the fisheries sector into modern, commercial and competitive to ensure more contribution to national development and poverty alleviation among the stakeholders (URT, 2015). The policy identified weak stakeholder's participation in data collection, analysis and dissemination among factors constraining the fisheries sector development. The government promises to improve the use of ICT in fisheries data collection, processing, storage and dissemination at all levels. Thus, the developed participation-reputation based incentive mechanism to encourage fisheries stakeholders highly and honestly, use the system would be a useful solution to achieve government mission of promoting stakeholder's participation. The multi-channel feature of this framework provides the fisheries community and other stakeholders an innovative, cheap and accessible platform for knowledge sharing, collaborations, Government policy and guidelines dissemination. Furthermore, the accessibility of the framework using widely owned ICT tools (mobile phone) by most fisheries stakeholders enables more participation in fisheries information collection and dissemination.

1.7 Delineation of the Study

Due to budget and time constraints, the project's case study was limited to Mwanza and the Mara region. We also didn't include aquaculture in the study; instead, we focused solely on freshwater fisheries.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Researches proved that Information and knowledge promotes innovativeness, productivity and competitiveness in the fisheries value chain. The ability of stakeholders to participate effectively and benefits from the sector are highly depending on their ability to acquire timely and accurate information about new practice, market prices and best fishing gears, new policies and guidelines. Literature review guided this research work towards its completion by firstly reviewing general information dissemination models. We then examined Agricultural information dissemination initiatives, fisheries information dissemination initiative, fisheries value chain and ICT tools used for information dissemination. Finally, we reviewed crowdsourcing information systems, incentive mechanism design and game theory applications in fisheries sector.

2.2 General Information Dissemination Models

Web Portal, Voice-based service, Text (SMS) based service, Self-support online community – information service, Interactive video conferencing service, Mobile internet-based service, and Unified multi-channel service model are the seven types of information dissemination models identified by Zhang *et al.* (2016).

Web portals are groupings of relevant websites that are hosted on a platform. It is a vital and quick means of disseminating information (Zhang *et al.*, 2016). The Ministry of Livestock and Fisheries Development and the Ministry of Agriculture, Food Security and Cooperatives both have websites that provide information on livestock and crops to various stakeholders in the country and around the world, thanks to the current universalization and application of web technologies (Gladnes & Fatma, 2014). However, these websites have focused much on information related to Livestock and agricultural information, excluding fisheries sectors.

The use of call center technology to provide users with professional advice and automated voice services is known as voice services. Users can call in for information and help on legislation, technology, marketing, business, and other professional and social issues (Zhang *et al.,* 2016). The SMS messaging service model is activated by agricultural information suppliers and telecommunication service providers (SP). Text messages are edited, audited, and published by the agricultural information supplier via the defined telecommunication channels.

According to Zhang *et al.* (2016), farmers and other interested parties can share information through online communities. Using the online support service paradigm, farmers and other agents can build a community to help one other. A farmer-to-farmer community can also be formed. Farmers enroll in the service system using authenticated personal information. Members of this online community service model include farmers, government officers, agriculture-technical specialists, industry associations, and agricultural corporations. Members of the community converse online using their laptops or mobile phones.

The video conferencing service paradigm is the use of the Internet for real-time video and voice communications. The most distinguishing features of this model are visual and face-to-face interaction, as well as multiple service approaches such as one-to-one service to provide real-time remote technical advice, one-to-many service to provide real-time remote classroom lectures, and many-to-many services, namely self-serving video courseware. Through the internet, farmers and agricultural specialists can connect one-on-one. The mobile Internet-based service distributes agricultural information to farmers on the interchange or at any agriculture production site.

The mobile information service is generally accessible, portable, and spatially recognizable. It is unconstrained in both time and space. The unified multi-channel service model includes both one-way information dissemination (e.g., portal, text message) and two-way information engagement (e.g., audio and video communications, online community, and mobile Internet service). Table 1 shows the advantages and disadvantages of each model, as well as some examples.

However, researchers have inspected information collection and dissemination concentrating on disaster pre-notice (Zhang *et al.,* 2014), crops cultivating (Barakabitze *et al.,* 2017; Etwire *et al.,* 2017; Tata & McNamara, 2017), animals keepers (Sanga, 2018) wellbeing part (Matingwina, 2016; Huang *et al.,* 2014). Scarcely any sorts of research have concentrated on the fisheries segment (FAO, 2020) and a large portion of them have considered single channel technique for social occasion and dispersing information.

Table 1: A summary of Information dissemination model analysis (Zhang *et al.*, 2016)

SN	Information service model	Operational Features	Application Examples	Advantages	Limitations
01	Web Portal	A collection of relevant web sites to form a one stop portal for users Model	China Minister of Agriculture Web Portal, Tanzania Ministry of Agriculture Web Portal	Easy access, comprehensive and in-depth information provision.	One for all information, No customization. May not be relevant to an individual user's specific information need
02	Voice-Based Service Model	Information dissemination through phones or online voice calls.	Liaoning 12316 Golden Farming	Interactive communications, easy to understand and individual service	Require human involvement, time consuming and less efficient, more costly
03	Text (SMS) based Services	Disseminating information via Mobile phone text	Hunan Agri-Telecom Platform	Push-based approach, very effective and efficient in sending short and timely messages	Cannot provide comprehensive and in depth information. One for all service. May not be relevant to individual user's specific information needs.
04	Online Community Model	A membership system involving all stakeholders, share experience and exchange information through interactive service platform	Farmers Mailbox in Zhejiang Province	Interactive communications, relevant information, user participation, cost effective service	Require active user participation, efforts and good management. Service is only available for members
05	Interactive Video Conferencing	Information dissemination using online conferencing service	Shanghai Farmers ''One Click and GO" service	Easy to understand, very effective communications, interactive service	Require human involvement can be time consuming and less efficient, costs is high due

SN	Information service model	Operational Features	Application Examples	Advantages	Limitations
					to the involvement of human experts
06	Mobile Internet Based Service	Information dissemination using Mobile internet service via smart phones	E-Price App	Ubiquitous, cost effective, easy access, can incorporate GPS technology to provide location related service.	Require adequate infrastructure and the use of smart device. Require higher IT skills to use new technologies
07	Unified Multi-Channel Service	Using multiple models to effectively disseminate information through telephones, computers, and Mobile phones	“ 3 in 1 Service” in Fujian	Flexible service combining advantages of all models	Require Investment in ICT infrastructure and equipment, require more effort and support from key stakeholders

2.3 Agricultural Information Dissemination Initiatives

Over the previous decade, both the public and private sectors have developed and distributed various ICT for agriculture activities. A tiny portion of these projects connected buyers and sellers or promoted access to financial services, but the bulk provided farmers and dealers with pricing, climate and specialized data (Nakasone *et al.,* 2014). Various Information Service Systems are currently delivering needed information to the right place and time for communities in Africa, the Caribbean, and the Pacific. According to Angello (2017), several initiatives have been involved in the innovation and development of these valuable services. One such initiative is Manobi, a Senegalese company that developed a real-time data collection system that uses the Internet and mobile technologies to track daily price fluctuations and produce deliveries to markets. Farmers can utilize the system to get information on finance and supply (seeds, insecticides, and fertilizers), as well as communication with extension programs, price details, processing, and packaging. The Kenya Agricultural Commodity Exchange (KACE), like Manobi, connected farmers, enterprises, and markets through a network of franchised market resource centers (MRCs). The centers provide KACE with up-to-date market data, as well as on-site Internet, email, and phone services, which are transmitted to farmers via SMS.

The DrumNet, a Kenyan project, runs a network of information access points, or 'info-kiosks,' that provide farmers with marketing, financial, and information services. Each info-kiosk is connected to a hub in Nairobi and has an Internet connection, a computer, and mobile phones. There, data from across the country is compiled in a central database and then sent via SMS to information kiosks and farmers. Nonetheless, human agents manually collected data across the country and compiled it in a central database before distributing it to farmers. The manual data collection process is costly exercise because it requires a large number of agents to travel across the country. It allows for human error and makes real-time information difficult to obtain.

Esoko is a mobile platform for farmers that was first established in Ghana and is now implemented and used in fifteen (15) nations across West and East Africa. Farmers may access agricultural market information such as updated produce pricing and current trends, weather forecasts and notifications, and crop output levels using this groundbreaking mobile application solution (David-West, 2010). Farmers have been able to increase their output and sell their food at the right price, at the right location, and at the right time thanks to the platform. The platform, on the other hand, only allows SMS, phone calls, and Unstructured Supplementary

Service Data (USSD). Supporting SMS, phone calls and USSD only becomes a restrictive factor as cheap and affordable smartphones are entering the market, and users may demand visual applications. The manual market agents for collecting information makes the system running cost high, too expensive, unaffordable to small-scale farmers, provide rooms for human errors, and hard to get real time information.

According to Gladnes and Fatma (2014), Tanzania has implemented several ICT projects with the goal of disseminating information to farmers. The Agricultural Marketing Systems Development Program (AMSDP) implemented the First Mile Project in Tanzania's northern and southern highlands between 2005 and 2009. To provide necessary information to farmers, the project uses SMS, voice calls, and the internet. Farmers were able to get timely and accurate market price information as a result of the project, which also improved communication between agricultural prayers and the local market. Agents, on the other hand, collect information manually around the region and combine it, making real-time market data and specific prices difficult to obtain. Another endeavor is mFarmer, a mobile phone-enabled agriculture information and advising service that was introduced in 2011 (The African Development Bank [AfDB], World Bank, 2012). Countries in Sub-Saharan Africa benefit from the mFarmer projects (Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Rwanda, Tanzania, Uganda and Zambia). The mFarmer sends agricultural information and advice to farmers' mobile phones via SMS.

Tanzania's Tigo mobile network operator created the Tigo Kilimo application (Palmer & Pshenichnaya, 2015). Farmers who have voluntarily subscribed through mobile phone can get agricultural information through four different mobile channels: USSD, push SMS subscription, Interactive Voice Response (IVR), and a helpline. The Tigo Kilimo and WiFARM programs provide agronomic suggestions on ten important crops (maize, rice, Irish potato, cassava, onions, banana, citrus, sweet potato, tomato and cashew), as well as market pricing information on the aforesaid crops for major marketplaces. Although the program can be tailored to the fishing business, it lacks the value chain integration and incentive mechanisms that would motivate users to participate honestly.

2.4 Fisheries Information Dissemination Initiative

The sustainability and development of the fisheries sector require an effective and efficient information exchange platform among fisheries resource users, managers and other stakeholders. Researchers from all across the world have presented many new strategies to meet these objectives. The National Aquatic Resources Research and Development Agency (NARA) in Sri Lanka recommended the establishment of a Fisheries Information Centre (FIC) (Wimalasena, 2016). The system provides timely and accurate information pertaining fisheries sector to all stakeholders through mobile phone calls. However, employing mobile phone calling involves availability of human interventions therefore increasing the running costs of the system. The ICT applications were produced by or for the African, Caribbean, and Pacific (ACP) Group of States, primarily by or for small-scale fisheries (Mallalieu, 2015). Table 2 provides a test of these with subtle elements, where accessible, approximately the goals, and addressed component within the value chain. Conversely, all these innovative solutions addressed challenges in one or two components of the fisheries value chain causing fragmentation along the chain.

Table 2: ICT applications developed for fisheries in ACP Countries

SN	Country	Name of Application	Objective of the Application	Fisheries Value chain
01	Trinidad & Tobago	mFisheries Navigation	To provide everyday support for sea- and large-riverine farers to assist with navigation; planning, viewing and notifications of trips; communicating with at-sea social networks and logging location-based data.	Harvest
02	Trinidad & Tobago	M.A.D.E. – My App for Disasters and Emergencies	To provide location-specific, actionable information about natural disasters, connect those in need with first responders, disaster response coordinators, and enabling optimally allocate resources.	Harvest
03	Haiti.	TERA – Trilogy Emergency Response Application	To enable aid broadly and swiftly disseminate messages relating to disaster relief	Harvest
04	Trinidad & Tobago	mFisheries W&T	To provide credible, scientific information concerning local weather, tide and moon phase to sea users	Harvest
05	Developed in Australia, customized for Caribbean countries	Caribbean Tide Times	To track tide times	Harvest
06	Developed in Australia	Pacific Islands Tide Times	To track tide times	Harvest
07	Developed in the US Customized for several Africa, Caribbean and Pacific countries	Buoy weather	To provide accurate long-range marine forecasts, charts and graphs, wind and weather data.	Harvest
08	Trinidad & Tobago	mFisheries Safety	To provide emergency support for fishers by geofenced tracking and alert.	Harvest

SN	Country	Name of Application	Objective of the Application	Fisheries Value chain
09	Developed in Kenya Customized for Kenya and parts of West Africa	EFMIS-Ke – Enhanced Fish Market Information Service	To enhance fish trade and incomes of the fisher community by improving access to market information	Market
10	Developed in Trinidad & Tobago Customizable to all countries	mFisheries- Virtual Marketplace	To provide mobile and web tools (virtual market) for easy communication between small-scale fisheries and processors.	Market
11	Trinidad & Tobago	mFisheries-Training Companions	To provide non-traditional learning opportunities through various media formats	Harvest & Training
12	Developed in Ghana	Radio Ada	To provide information and communication services to strengthen fishers' livelihoods and linkages with advocacy groups and civil societies	harvest, Organizational, and markets
13	Southern African	WWF-SASSI application	To inform and educate all participants in the seafood trade, from wholesalers to restaurateurs through to seafood lovers on sustainable fishing and fish species.	Harvest, Processor, and Market
14	Developed in Kenya	Tracefish-Ke	To establish an electronic traceability system for Nile perch from Lake Victoria and seafood products from marine fisheries	Harvest, Process and Market
15	Developed for Solomon Islands	Digital Deck, HapiFish	Mobile data capture at sea, access to catch history, meeting agency logbook requirements and to track progress towards fishery management goals.	Harvest

Mallalieu (2015)

2.5 Fisheries Value Chain

Mallalieu (2015) defines a value chain as a connected arrangement of exercises that maps the turn of events and additionally development of an essential item from its source right to the consumer. Value chain analysis (VCA) infers significant determinants of worldwide income distribution, expenses and bottlenecks of each sequenced movement related with collecting, harvesting, handling, production/processing distribution and sales.

Researchers have conducted Value Chain Analysis (VCA) for the fisheries segment over the previous decade with each adjusted for the setting under examination (Bjorndal *et al.,* 2014; Sweenarain, 2012a; Sweenarain, 2012b). These analyses reveal that the VCA's structure differs significantly depending on the species and the market's ground actual elements. The VCA's composition varies according on the market's breadth, such as whether it is domestic, regional, or international.

The increased usage of the fisheries value chain, which encompasses social, cultural, political, and institutional aspects, is of particular importance to fisheries stakeholders. The VCA, when properly formulated, can help to inform policies that address imbalances in the fisheries ecosystem. These broader perspectives on the value chain necessitate increased partner commitment and participatory administration as a means of strengthening the multi-stakeholder ecosystem and its various elements.

Mallalieu divides the value chain of fisheries into two categories: Horizontal and vertical value chains (Mallalieu, 2015). As shown in Fig. 1, the horizontal value chain is a typical model that depicts the transmission of harvested fish via a variety of stages of sale, value addition, and consumption. The value chain begins in the marine or aquaculture environment and ends at the point of consumption. Physical/Instrumental, Informational, Processes/Transactional, Organizational, and Strategic are the five tiers of the vertical value chain. Every step of the horizontal value chain, as well as every level of the vertical value chain, adds value to the caught fish. The deployment of innovations to establish broken linkages between vertical value chains for each movement along the horizontal value chain, as shown in Fig. 1, is a critical opportunity for harnessing current ICT skills in the fisheries sector. Strategically applying ICT to link horizontal and vertical value chain facilitates fundamental knowledge management and communications among fisheries stakeholders in policy cycle as presented in Fig. 2.

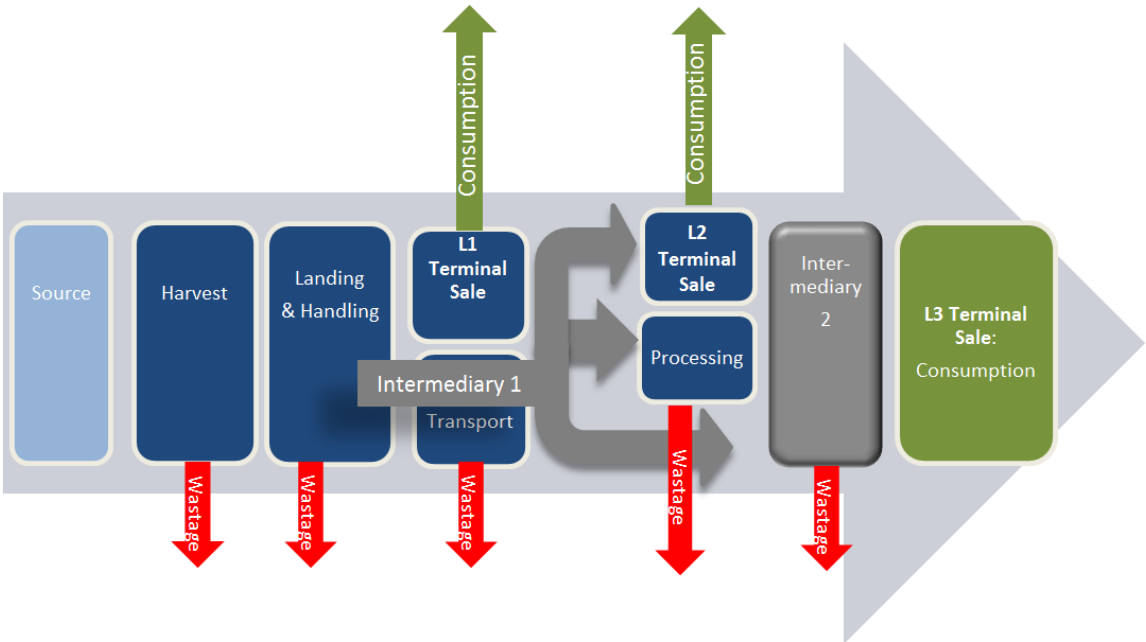


Figure 1: **Generic model of fisheries value chain (Mallalieu, 2015)**

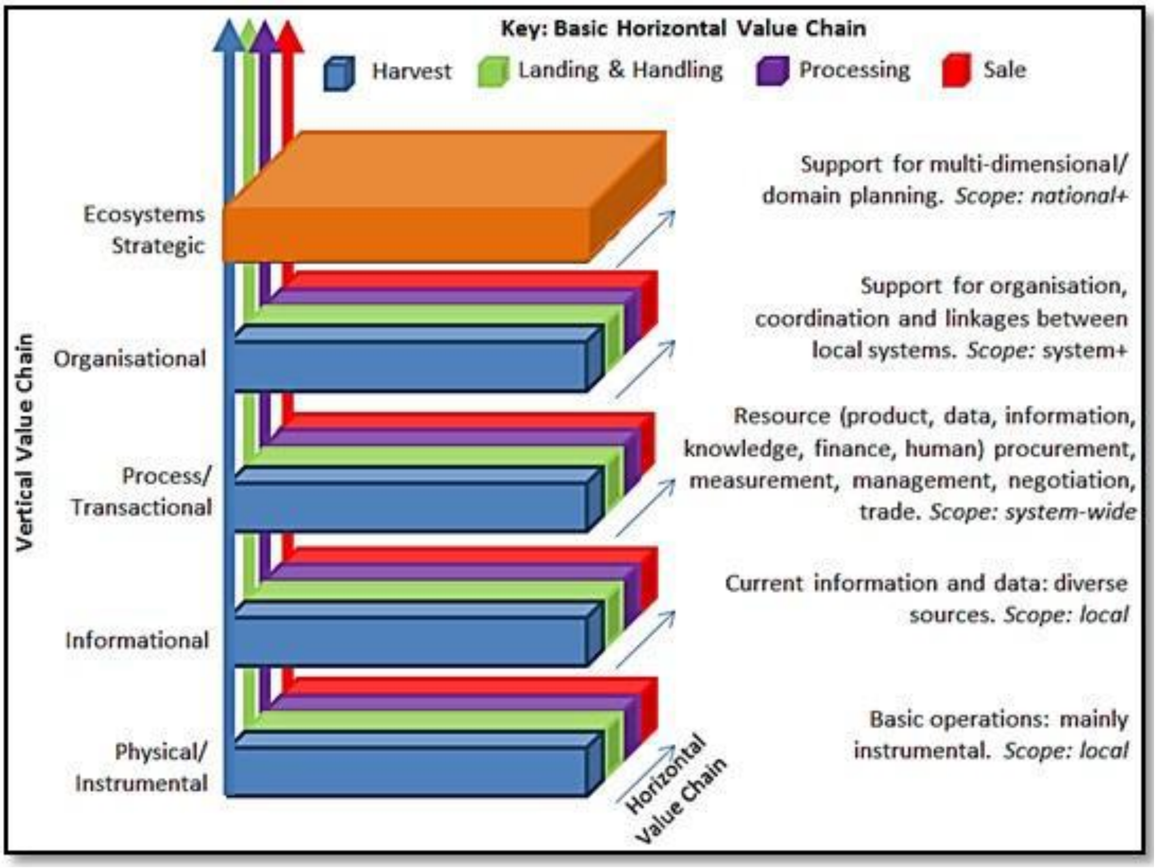


Figure 2: **Central focuses for ICT mediations in fisheries value chain (Mallalieu, 2015)**

2.6 Sources of Fisheries Data and Information

Fishers and traders have traditionally gotten data from a variety of sources, including their claim trial and error, neighborhood social systems, rural extension administrations, and broadcast media, such as radio. Study conducted in Nigeria by Uzezi (2015) revealed that personal experiences, extension officers, television, radio, newspapers, library, neighbors, exhibitions, fisheries department and community meetings are the main sources of fisheries information. Nevertheless, study also revealed that limited number of extension officers and inadequate ICT infrastructure hinders smooth flow of fisheries information. According to Annune *et al.* (2014), personal experience, traditional fishing festivals, community fishing competitions, fishing cooperatives, market places and personal contact are all sources of fisheries information. According to Tanzania national fisheries policy, sources of fisheries information are Ministry of Livestock and Fisheries development, Local government authority, Non-government organization, Community based organization, Research Institution, Extension officers, Fish traders and fishermen (URT, 2015). The strategic use of ICT in fisheries sector will facilitate effective knowledge management and communication, hence support data generation, data analysis, advice generation, decision making, policy implementation and policy review and evaluation as depicted by Fig. 3.

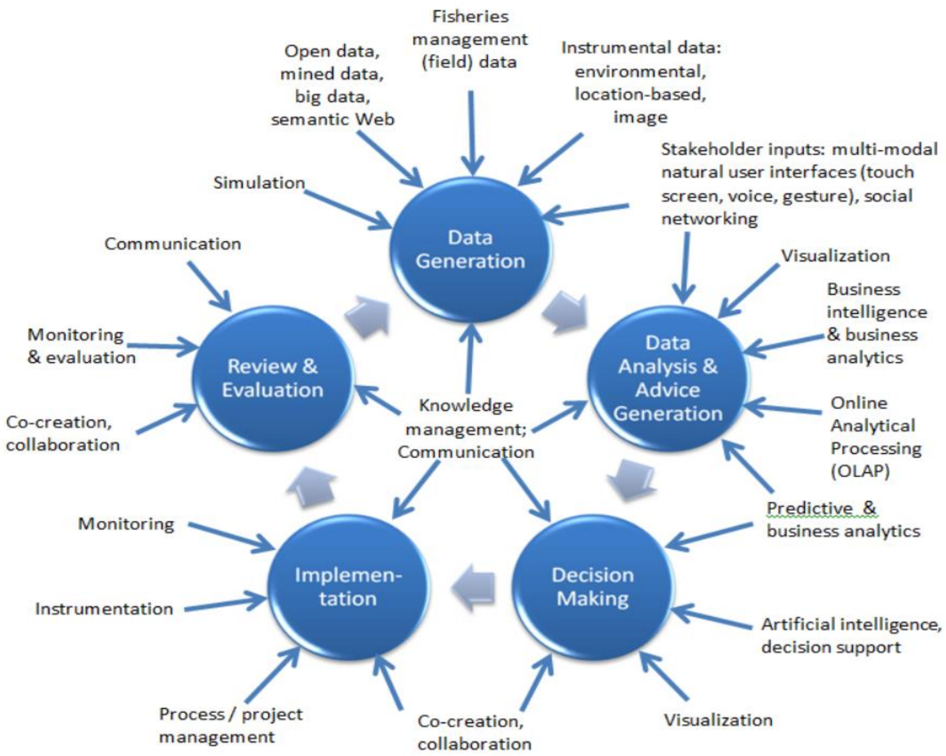


Figure 3: ICT support in Fisheries Policy cycle (Mallalieu, 2015)

2.7 ICT Tools Used for Information Dissemination

According to Qureshi *et al.* (2014), the internet, mobile phones, radio and television are the most important sources of communication for farmers seeking information and data. Study conducted in northern Pakistan shows that, television, radio, mobile phone and internet are useful channels for receiving information among farmers (Aldosari *et al.*, 2019). Other studies advocate that farmers mostly part utilizes mobile phone innovation to secure data to improve productivity, efficiency, anticipate plant illnesses, and develop superior promoting techniques (Bhandari *et al.,* 2014; Carmody, 2013; Chhachhar *et al.,* 2014; Heeks, 2012; Ogbeide *et al.,* 2015; Ezra *et al.,* 2018). However, limited studies examined mobile phone use in small-scale fisheries. Most research focused on mobile phone application in agriculture (Balraj & Pavalam, 2012; McCole *et al.,* 2014; Nwaobiala & Ubor, 2016; Fadairo *et al.,* 2015; Arinloye *et al.,* 2015). Landline telephones, cell phones, and the internet are all key mediums for accessing and disseminating information, according to a study done in Haryana, India (Kumar & Kumar, 2018).

2.8 Crowdsourcing Information System

In a Wired Magazine story from 2006, Jeff Howe first coined the phrase "crowdsourcing" (Howe, 2006). Various academic and business community researchers have expressed interest in the concept. Howe described crowdsourcing as the practice of outsourcing a task performed by an employee to a broad, unspecified group of people outside the company (Howe, 2008). Crowdsourcing, is a way in which organizations use a strategic display to attract interested and persuaded people to supply arrangements in quantity and quality that are often satisfied by traditional organizational structures and processes (Brabham, 2009). Both Howe and Brabham emphasized that under crowdsourcing, the job is done by the general public rather than by inside employees. Crowdsourcing were defined by Estellés-Arolas and González (2012) as a participatory online accomplishment in which an individual or organization suggests the voluntary undertaking of a job to a group of individuals or organizations of varying acquaintance and heterogeneity via a flexible open request. According to Sanga *et al.* (2016), crowdsourcing is facilitated through the use of ICT to harness the science, talents, and efforts of a global population of individuals. Furthermore, Sanga *et al.* (2016) defines crowdsourcing as a method of obtaining services by soliciting online contributions from either paid or unpaid persons. Crowdsourcing has a lot of benefits, including access to high-quality ideas, knowledge, skills and solutions from a huge number of individuals around the world (Blohm *et al.,* 2013; Brabham *et al.,* 2014; Brabham, 2013).

Cooperative crowdsourcing, competitive crowdsourcing (Bayus, 2013; Pedersen *et al.,* 2013; Zhao & Zhu, 2014) and candidate crowdsourcing are the three main types of crowdsourcing information systems (Ye & Kankanhalli, 2013). Users can contribute and collaborate in the provision of tasks and ideas through cooperative crowdsourcing (Bayus, 2013). Di *et al.* (2010) and Jeff (2006) suggested that communication and collaboration among users, as well as between the organization and users, be maintained across time, and that these interactions take place on intermediary platforms. These intermediary platforms act as information systems, assisting organizations in building networks with users and collecting knowledge, technologies, solutions and other important information (Ye & Kankanhalli, 2013). For new products, users freely offer ideas and assist in task formulation. They participate because they care about the brand, not for the money. Users get products and services that better meet their requirements, knowledge and abilities relevant to their interests, joy, and personal fulfillment in exchange for participating in this process (Djelassi & Decoopman, 2013). The key motivations for users in cooperative crowdsourcing are these remunerations. Dell's Idea Storm is an example of a cooperative platform (Bayus, 2013).

Competitive crowdsourcing permits users to select tasks and submit concepts at their determination. Organization can then select and remunerate the best idea that might be a single submission or a teamwork (Terwiesch & Xu, 2008). Blohm *et al.* (2018) supposed that competitive crowdsourcing is more appropriate to solve certain organization problems faster, better, and cheaper than companies are able to solve it in-house. Users hardly cooperate or collaborate with others, but may have some communication with organization agents. Crowdsourcing information systems assists organization issue tasks to users and choose the best one from several users' submissions. It ensures users submit suggestions individually without being predisposed by others (Ye & Kankanhalli, 2013). The user's main incentive for contending in crowdsourcing tasks is to win the competition and earn monetary prizes (Zheng *et al.,* 2014).

Candidate crowdsourcing systems enables organization to choose contenders and collaborate thoroughly with them to complete the required tasks (Bullinger *et al.,* 2010; Morgan & Wang, 2010). Candidate crowdsourcing systems are appropriate for tasks that require close and long-term cooperation between organization and particular associates (Ye & Kankanhalli, 2013). This kind of systems enables organization to select applicants, form connection with them, and share knowledge through the platform. Nevertheless, organizations are encouraged to provide more time and energy to nurture cooperation and knowledge sharing amongst organization and contenders. The prime incentive for contenders is to earn money.

Crowdsourcing has found applications in different areas by employing different technologies like World Wide Web (Doan *et al.,* 2011) and mobile phones (Chatzimilioudis *et al.,* 2012). An applications known as "askus", "fashism" and "Ushahidi" developed and used in Kenya are examples of mobile phone use in crowdsourcing (Alt *et al.,* 2010). The United States

Agency for International Development [USAID] briefing paper presented different areas of agricultural development in Africa benefitted from crowdsourcing applications (USAID, 2013). Mobile and web-based agricultural market information systems known as MFarm and mobile gestation calendar known as iCow developed in Kenya are examples of crowdsourcing application in agriculture. The ABALOBI program was created in South Africa using open source software to monitor, track, and collect data from small-scale fishermen (Petrik & Raemaekers, 2018). Kenya (EFMIS-Ke) is a virtual marketplace program aimed at allowing fisherman to obtain market information and reducing poverty by increasing transparency in prices (Mallalieu, 2015). The HapiFish is a mobile phone application developed in the Solomon Islands to provide fast and efficient access to market and biological data (Mallalieu, 2015). Esoko, a Ghanaian ICT platform intended specifically for crop farmers to simplify data collection, market information, and payments, can be adjusted for fishers (Schalkwyk *et al.,* 2017). Another application of crowdsourcing is the verification of local weather information, as well as the community purchasing and selling of agricultural products. Buoy weather is a long-range marine forecasting system developed in the United States and modified for Africa, the Caribbean, and the Pacific. It includes charts, graphs, wind speed, and other weather data (Mallalieu, 2015).

Despite many benefits of crowdsourcing application in various areas of agriculture, researchers pointed out challenges in crowdsourcing implementation. The challenges include user's management, quality control and abuse management (Doan *et al.*, 2011), skilled expert, data quality, Privacy issues and priorities (Alt *et al.,* 2010). Another issue is that participating in a crowdsourcing system like this usually comes at a fee to individual users. Such fees could be based on a user's resource consumption, such as processing power, battery life, airtime, or an internet bundle. On the other hand, the system may necessitate the input of some of the users' sensitive private information, thus exposing their personal information. Fishermen, for example, demonstrate their regular earnings by sharing their daily earnings. Fishermen frequently reveal information about their whereabouts when they report a landing site. As a result, without adequate incentives to offset the costs of participation, people will be hesitant to use such systems. The majority of existing innovation platforms rely on user participation that is voluntary and lacks appropriate incentive mechanisms.

2.9 Game Theory Applications in Fisheries Sector

For long time game theory has mostly been used as standard analysis tool in economics (Hannesson, 2011). However, there are many economics problems that can be analyzed successfully without the application of game theory. But for most competitive problem where tactical interactions are very imperative such as interaction among sovereign states, game theory is obligatory. But since the late 1970's game theory has been applied in fisheries sector. However most previous literatures on game theory application in fisheries focused specific settings of international fisheries (Pintassilgo *et al.,* 2014; Lindroos & Kronbak, 2006; Lindroos, 2008). Other fisheries problems of interest to which game theory could be applied include competition in fish markets, regulators and fishermen, boat and net owners, net owners and fishing crews, fishermen and fish traders, fish traders and fish processors, information gathering and dissemination among fisheries stakeholders.

2.10 Incentive Mechanism Design

The man, machine, money, technique, material, and marketing qualities of an organization can be solved through crowdsourcing (Wulandari & Rahmah, 2020). Users of crowdsourced nature systems, on the other hand, will be hesitant to utilize the system, provide information, or provide feedback if they are not sufficiently encouraged to do so via an effective incentive mechanism. Researchers have worked hard to develop a number of incentive methods to motivate crowdsourcing system users to solve this problem. Zhang *et al.* (2016) looked into several incentive schemes that enticed users to participate in crowdsourcing nature applications and divided them into three categories: amusement, service and money. Another study Zhang *et al.* (2014) offered three incentive mechanisms: Threshold-based auction (TBA), honest online incentive (TOIM), and truthful online incentive non-zero arrival-departure (TOINZ-AD). The TBA mechanism attempted to maximize the utility of the user, whereas TOIM and TOIM-AD aimed to strike a balance between utility maximization and veracity.

A truthful and budget-friendly mechanism focusing on the severe budget constraint was also proposed (Zhang *et al.,* 2015). Finally Wen *et al.* (2015) suggested a quality-driven auction-based reward mechanism to incentivize user participation. They used data quality as a criterion to encourage system participants in their suggested incentive mechanism. However, in their proposed mechanism, these researchers failed to account for both providers and requesters' participation and honesty.

2.11 Conclusion

Given the absence of evidence for game theory intervention in addressing dishonest behavior in fisheries information sharing, this study developed an evolutionary participation reputation incentive game model (EPRIGIM). The researchers performed a series of simulated tests to see how incentives and penalties might encourage and discourage honesty and dishonesty, respectively. Confirmation of EPRIGM's applicability will serve as a starting point for the creation of a useful fisheries data collection and dissemination system.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The research approach employed in this study is summarized in this chapter. The study design, target population, sample technique, data collection tools, data analysis tools and presentation are all included in this section. This research approach was created to assist the researcher in gathering and processing data.

3.2 Design Science Research Methodology

This study employed a design science research methodology (DSRM) adopted and modified format by Peffers (2007). The DSRM was selected owing to its capability to resolve problem focusing on investigation and formation of artifacts. Centered on the main objective of this study, design science research methodology provided the necessary framework for the development of an evolutionary game-theoretical model for trustworthy multi-channel information gathering and dissemination framework among fisheries stakeholders of Mwanza and Mara regions of Tanzania.

Table 3 depicts the modified format of the DSRM. The first column lists the six activities that contribute up the DSRM sequences. Column two provides details explanations of each activity, third column describes the required knowledge base to execute each activity and the fourth column describes each activities output. These integration of the knowledge base improves the DSRM by enabling researcher to look for most effective knowledge tools, explain their selection and describe how they are applied to solve the problem (Geerts, 2011).

Table 3: Design science research methodology

Sn	DSRM activities	Activity description	Knowledge base	Outputs
1	Problem identification and motivation	*What is the problem?* Define the research problem and justify the value of a solution.	Understand the problem's relevance and Its current solutions and their weaknesses.	Concept note
2	Define the objectives of a solution	*How should the problem be solved?* In addition to general objectives such as feasibility and performance, what are the specific criteria that a solution for the problem defined in step one should meet?	Knowledge of what is possible and what is feasible. Knowledge of methods, technologies, and theories that can help with defining the objectives	Proposal
3	Design and development	*Create an artifact that solves the problem.* Create constructs, models, methods, or instantiations in which a research contribution is embedded.	Application of methods, technologies, and theories to create an artifact that solves the problem	Artifact
4	Demonstration	*Demonstrate the use of the artifact.* Prove that the artifact works by solving one or more instances of the problem.	Knowledge of how to use the artifact to solve the problem.	Prototype/ Simulation

Sn	DSRM activities	Activity description	Knowledge base	Outputs
5	Evaluation	*How well does the artifact work?* Observe and measure how well the artifact supports a solution to the problem by comparing the objectives with observed results.	Knowledge of relevant metrics and evaluation techniques.	Performance Measure
6	Communication	Communicate the problem, its solution, and the utility, novelty, and effectiveness of the solution to researchers and other relevant audiences.	Knowledge of the disciplinary culture.	Thesis, Journal, conference papers, and posters

The adopted and modified DSRM model in this study involve six process steps (Fig. 4) were aligned with the specific research objectives.

(i) Problem Identification and Motivation

In this step the study focused on reviewing literatures from various existing research work. The purpose of reviewing literatures was to create a clear understanding of research problem, build a theoretical knowledge base related to specific research questions to be answered by this study and determine the scope of the study.

(ii) Define the Objectives of a Solution

In this step the researcher conducted comprehensive literature reviews to facilitate the required knowledge acquirement. Various existing knowledge related to development of an evolutionary game theoretical model for trustworthy multi-channel fisheries information gathering and dissemination were surveyed in academic journals, books and reports from research organizations. Databases such as ResearchGate, Elsevier, Association for Computing Machines (ACM), Science Direct, Springer, IEEE, Tailors and Francis, Wiley and others were used during article search. The key words used during article search included but not limited to information dissemination, incentive design, game theory application in fisheries and crowdsourcing technique. The material considered were from 2013 to 2020 for journal papers, conference papers, workshop papers and report from research organizations. There were no limitations for books and theoretical materials.

(iii) Design and Development

During this step the focus was on the designing and developing an evolutionary game theoretical model for trustworthy multi-channel fisheries information gathering and dissemination. The process involved framework formulation, model formulation, and model coding. Empirical work was conducted to facilitate an evolutionary game theoretical model for trustworthy multi-channel fisheries information gathering and dissemination development. The empirical work comprises of channel information gathering and dissemination effectiveness analysis, architectural framework design and formulation, model formulation and model coding.

(iv) Demonstration

In this step focus was to prove that the developed artifact work perfectly to solve the intended problems. The developed evolutionary game theoretical model for trustworthy multi-channel fisheries information gathering and dissemination was simulated using randomly created dummy data. The simulation experiment was conducted five times using different number of randomly created data varied from 20 to 500. The simulation experiment implemented a maximum of fifty iterations in each experiments.

(v) Evaluation

The focus in this step was to assess the performance of the developed evolutionary game theoretical model for trustworthy multi-channel fisheries information gathering and dissemination in addressing the dishonest behavior of the stakeholders during information gathering and dissemination interaction. On every simulation experiment iteration, the reputation of stakeholders was calculated and results presented in line chart graph. The simulation experiment results (line chart graphs) were then compared.

(vi) Communication

The results and findings of this study were effectively communicated to technical and managerial audiences through journal publications, conferences, workshops, seminars and poster presentations.

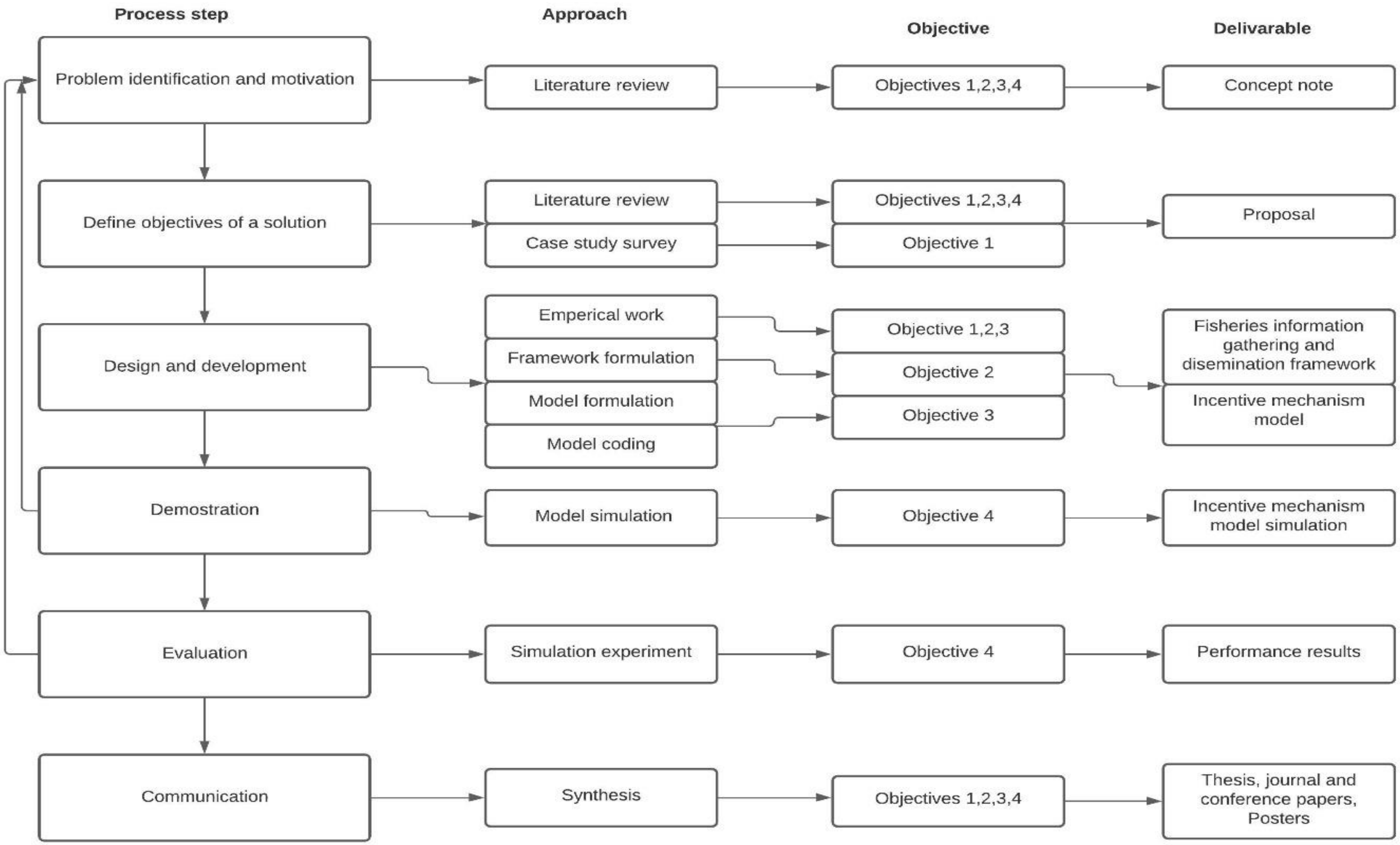


Figure 4: Design science research method process

3.3 Area of Study

This study was carried out in Mwanza and Mara regions from January 2019 to April 2019. It involved four Districts namely Ukerewe, Ilemela, Nyamagana (Mwanza region) and Musoma (Mara region). The four districts were selected because; their economy is largely tied up to fisheries activities. The researcher visited seven land sites for data collection namely: Chifule, Malelema (Ukerewe), Igombe, Kayenze (Ilemela), and Mwilengo, Bushora, Bwai (Musoma). We also collected data from Kirumba International Fish Market (Ilemela) and Musoma Fish Market.

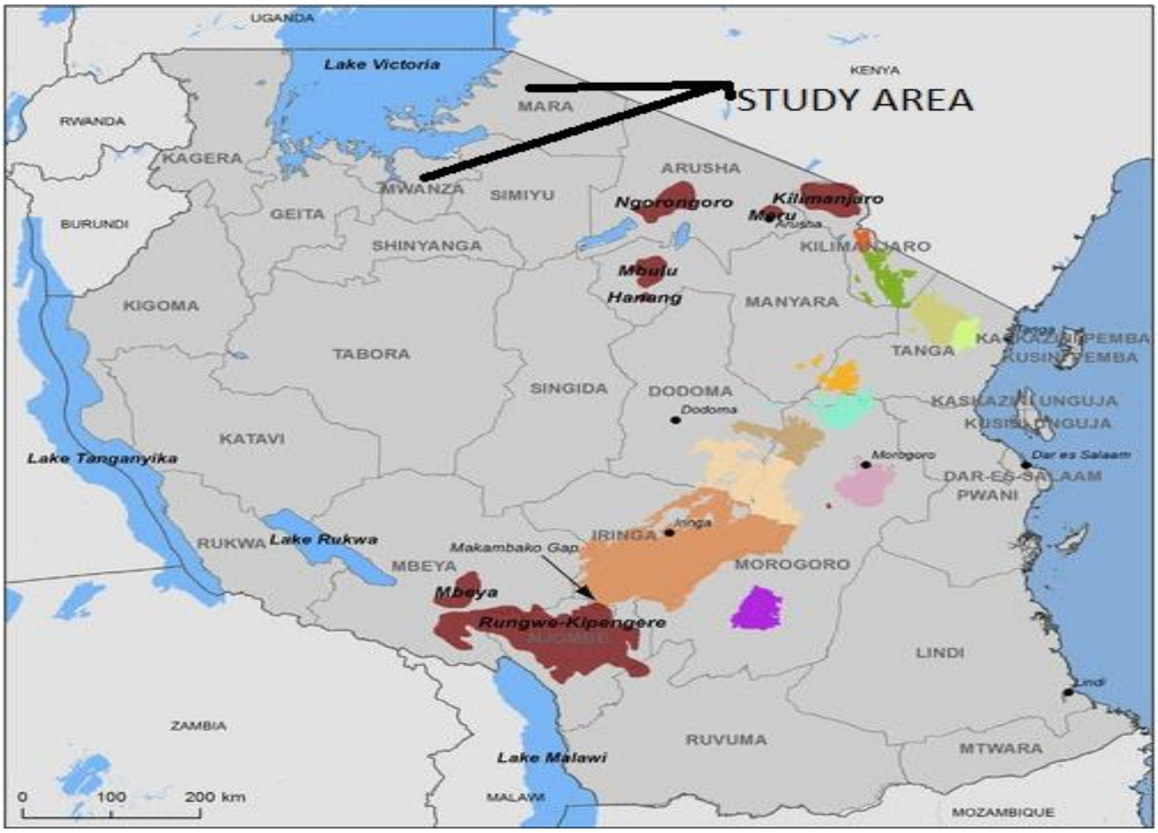


Figure 5: Map of Tanzania showing the study area

3.4 Targeted Population

The target population of this study was all fisheries stakeholders of the two regions (Mwanza and Mara). According to National Fisheries Policy (2015), fisheries stakeholder is any individual or organization that has an interest in any fisheries activities or fisheries products. These stakeholders were categorized in three groups namely fishermen, fish-traders and fisheries officer. The fishermen group includes net owners, boat owners and fishing crews. Fish-traders includes intermediary, fish processors, consumer and fish transporters.

3.5 Sampling Method

This study employed mixed sampling method to collect data. We employed purposive sampling (Non-probability) to select the four Districts namely Ukerewe, Ilemela, Nyamagana (Mwanza region) and Musoma (Mara region). The four districts were selected due to the fact that; their economy is largely tied up to fisheries activities. According to Kothari (2004), quota, purposive, convenience and snowball sampling are all form of non-probability-sampling methods. However, quota and purposive sampling are almost identical except that in purposive sampling there is no overall sampling design that tells the number of each type of informant needed for a given study (Kothari, 2004). The study also employed the same purposive sampling to select the seven land sites and the two fish market visited for data collection namely: Chifule, Malelema (Ukerewe), Igombe, Kayenze (Ilemela), and Mwilengo, Bushora, Bwai (Musoma) and Kirumba International Fish Market (Ilemela), Musoma Fish Market. In purposive sampling, items are chosen to be part of the sample with a specific purpose in mind. With such kind of sampling method, researcher believed that some items are better fit for the research compared to other individuals. The process involves purposely-handpicking items from the population based on the authorities or the researcher's understanding and decision. Individual respondent was randomly selected.

3.6 Sample Size

Since the total population of fisheries stakeholders are not known, we used the formula (1) to estimate sample size for infinity (Unknown) population proposed by Kothari (2004) to estimate sample size for this study.

$$n = \frac{z^2 p * q}{e^2} \qquad (1)$$

Where,

z – The value of the standard variant at a given confidence level

p – Standard Deviation

e – Margin error

q = 1-P

Since the intended confidence level of this study was 95%, the derived Z-score is 1.96, standard deviation of 0.5, and margin error of 0.05. Substituting this value in the given formula yield 384 samples.

3.7 Data Collection Tools and Method

This study used both secondary and primary data. The data collection tool used was documentary reviews and structured questionnaire distributed to respondents and collected back. The researcher obtained Secondary data from the Tanzania Communication Regulatory Authority (TCRA) website and collected primary data from Ministry of Livestock and Fisheries Development, Mwanza and Mara regions. In this study (450) questionnaires was distributed and managed to collect back (400) questionnaires as described in Table 4 and 5.

Table 4: Questionnaire distribution

Region	**Number of questionnaire**
Mwanza	350
Mara	100
Total	**450**

Table 5: Distribution of respondents

Respondent Group	**Number of respondent**
Fisheries Officer	45
Fisherman	230
Fish Trader	125
Total	**400**

3.8 Validity and Reliability of Study Instruments

Validity denotes to the degree to which confirmation and principle supports the understanding of the test scores (Saunders, 2009). The researcher consulted a team of data collection tools experts who assisted in reviewing our instrument to ensure that it conform to standard in both content and appearance validity. Managed to developed the study research instruments in line with the reviewed literature. According to Mugenda and Mugenda (2003), 10% of the sample size is adequate for a pre-test study. Grounded on this argument, researcher pre-tested the questionnaire reliability before administering the survey with 40 stakeholders comprising of 15 fish traders, 20 fisherman and 5 extension officers at Ilemela district who did not form part of the study sample size. The pre-test survey was aiming to determine the effectiveness of the questions in our data collection tool. Pre-test survey results enabled the revision and improvement of the questionnaire to suit the survey requirement.

3.9 Data analysis Tool and Presentation

The data analysis process started with data cleaning by checking the completeness and accuracy of the collected questionnaire. After thoroughly inspection, sixteen (16) questionnaires were discarded due to incompleteness of its response. The researcher coded the collected data and digitized it using Open Data Kit (ODK) collect application. The analysis was performed using python panda libraries and presented our results finding using graphs and charts.

3.10 Channel Information Gathering and Dissemination Effectiveness

To analyze the effectiveness of six different channels (short Message services, Cellular phone call, Television, Radio, mobile application and Website) for fisheries information dissemination, this study calculated six different channels usefulness dissemination probabilities for each channel. This study introduced the following parameters in calculating different channels usefulness dissemination probabilities: Channel Coverage ratio (CR), Listening ratio (LR), Watching ratio (WR), Channel Access ratio (AR), Average access time ratio (AT), Information Usefulness ratio (UR) and Information Sharing ratio (SR). The effective dissemination probability of a given channel is related to channel coverage ratio, listening ratio or Watching ratio, Channel access ratio, Average access time ratio, information usefulness ratio, and information sharing ratio for a given stakeholder group. Listening ratio (LR), Watching ratio (WR), Channel Access ratio (AR), Average access time ratio (AT), Information Usefulness ratio (UR), and Information Sharing ratio (SR) were calculated based on data obtained from the survey questionnaire. Researcher obtained the channel coverage ratio (CR) from Tanzania Communication Regulatory Authority (TCRA) year 2019, fourth-quarter report available in their official website updated quarterly in a year. The ratios were calculated using Equation (2).

$$Ratio = \frac{Listerning/Watching\ respondent}{Total\ \ respondent} \tag{2}$$

3.11 Channel Information Gathering and Dissemination Process

The different channel has different information dissemination process. To understand the information dissemination process of each channel among the six channels (short Message services (SMS), flow chart of each channel was created, as shown in Fig. 6. Figure 6(a), 6(b), 6(d), and 6(f) shows the dissemination process flow of cellular phone calls, Mobile application, SMS and website respectively. Probability P1, P2, P3 and P4 are assigned to status connect, receive, usefulness, and share, respectively. The P1 expresses the probability of the stakeholder's cell phone to connect per day calculated by Equation (3). Since any stakeholder phone can either be on or off when fisheries information is sent at any time, thus P2 express the probability of receiving fisheries information (P2=0.5), P3=UR express the probability that received information is useful and P4=SR express the probability that received information is shared to others.

$$P1 = AR * CR * LR * AT \quad (03)$$

Figure 6(c) and 6(e) show the dissemination process flow of Radio and Television respectively with probability P1, P2, P3 and P4 assigned to status Listen /Watch, receive, usefulness and share respectively. The P1 express the probability of stakeholder to listen/watch Radio or Television per day calculated by Equation (3), P2 shows the likelihood of receiving fisheries information (P2=0.143), P3=UR express the probability that received information is useful and P4=SR express the possibility that received information is shared to others. Based on Fig. 5, Equation (04) describes the sufficient information dissemination probability of a channel expressed as EPC. Tables 6 and 7 respectively show the detailed results of calculated information dissemination parameters and sufficient dissemination probability for each channel. Researcher analyzed the calculated dissemination effectiveness probability of the six-channel against each stakeholder using python library. Python Plotly library was used to visualize the comprehensive comparison of the six channels effectiveness probability.

$$EPC = P1 * P2 * P3 * P4 \quad (04)$$

Table 6: Calculated service parameters for six channels

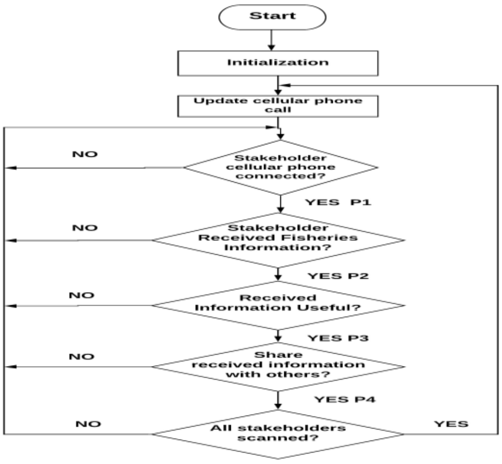
Channel	Fisherman						Fish traders						Fisheries Officers					
	C_R	L_R/W_R	A_R	A_T	U_R	S_R	C_R	L_R/W_R	A_R	A_T	U_R	S_R	C_R	L_R/W_R	A_R	A_T	U_R	S_R
Website	0.43	0.010	0.050	0.67	0.9	0.650	0.43	0.420	0.450	0.67	0.4	0.56	0.43	0.780	0.970	0.67	1	0.36
Television	0.76	0.020	0.120	0.125	0.9	0.650	0.76	0.030	0.220	0.125	0.4	0.56	0.76	0.030	0.210	0.125	1	0.36
Radio	0.85	0.037	0.142	0.125	0.9	0.650	0.85	0.035	0.254	0.125	0.4	0.56	0.85	0.045	0.196	0.125	1	0.36
Cellular call	0.81	0.890	0.920	0.67	0.9	0.650	0.81	0.950	0.980	0.67	0.4	0.56	0.81	0.920	1	0.67	1	0.36
SMS	0.81	0.890	0.920	0.67	0.9	0.650	0.81	0.750	0.980	0.67	0.4	0.56	0.81	0.854	1	0.67	1	0.36
Mobile App	0.43	0.245	0.340	0.67	0.9	0.650	0.43	0.890	0.980	0.67	0.4	0.56	0.43	0.854	1	0.67	1	0.36

KEY: C_R-Channel Coverage ratio LR-Listening ratio WR- Watching ratio AR-Channel Access ratio A_T- Average access time ratio
U_R- Information Usefulness ratio S_R- Information Sharing ratio

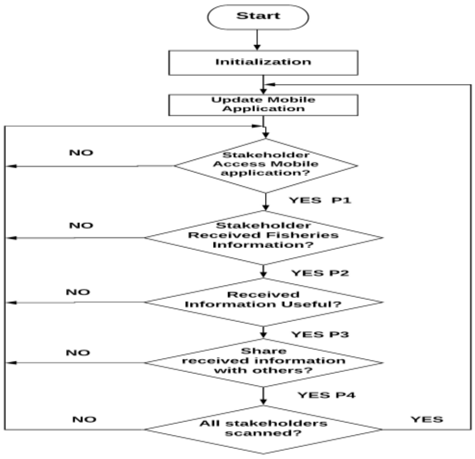
Table 7: Calculated Effective dissemination probability for six channels

Channel	Fisherman	Fish Traders	Fisheries Officers
	P_F	P_T	P_O
Website	0.042E-3	6.1E-3	39.2E-3
Television	0.019E-3	0.02E-3	0.031E-3
Radio	0.047E-3	0.03E-3	0.048E-3
Cellular Call	129.98E-3	56.59E-3	89.87E.3
SMS	129.98E-3	44.68E-3	83.42E-3
Mobile Application	14.04E-3	57.44E-3	88.57E-3

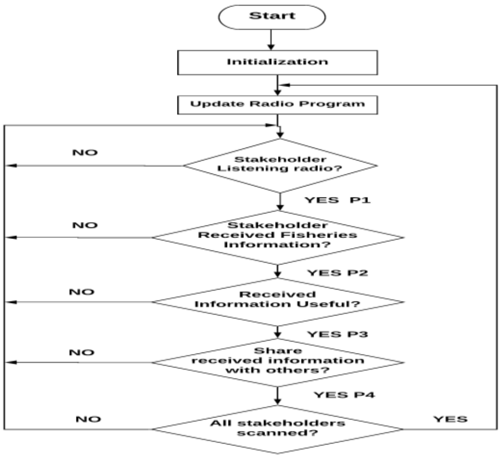
KEY: P_F- Effective Dissemination Probability of Fisherman P_T- Effective Dissemination Probability of Fish Traders
P_O- Effective Dissemination Probability of Fisheries officers



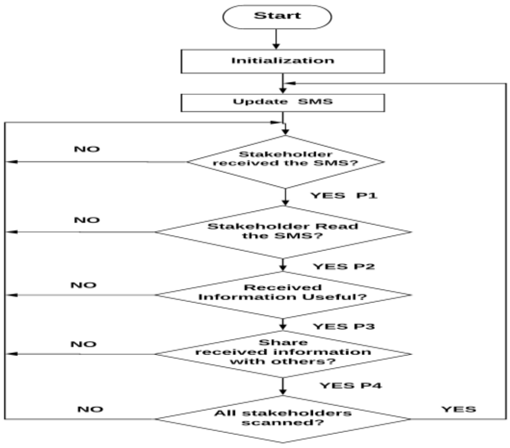
(a)



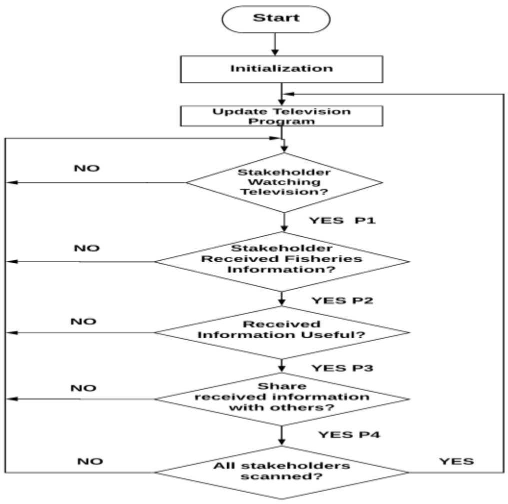
(b)



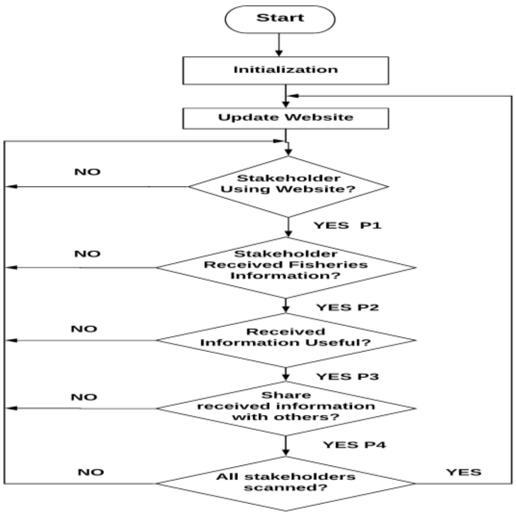
(c)



(d)



(e)



(f)

Figure 6: **Channel dissemination process flow charts. (a) Cellular phone call dissemination process flow chart. (b) Mobile application dissemination process flow chart. (c) Radio dissemination process flow chart. (d) SMS dissemination process flow chart. (e) Television dissemination process flow chart. (f) Website dissemination process flow chart**

3.12 Evolutionary Participation-Reputation Incentive Game Model Development

At any one time, the generic EPRIGM model (Fig. 7) comprises of an information gathering and dissemination system server and fisheries stakeholders, who are classified as information providers and users, respectively. The information user can upload data using one of four ICT channels: Mobile application, short messaging service (SMS), unstructured supplementary service data (USSD), or web application. The information user, on the other hand, can access information and provide comments through any of the same methods. During system interaction, fisheries stakeholders can play one of two roles (information providers or information users).

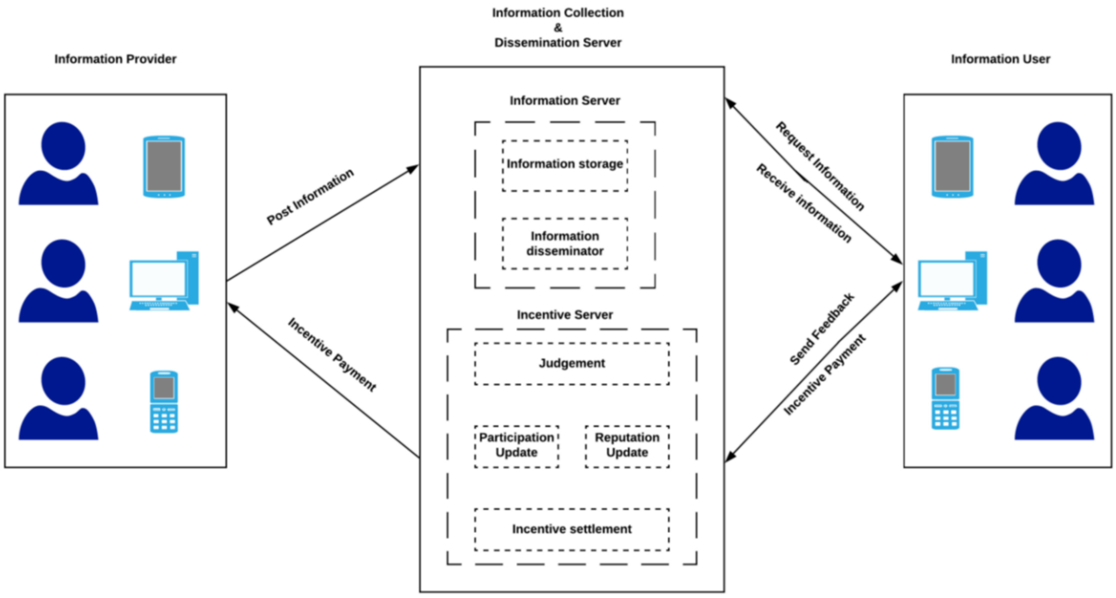


Figure 7: PRIGM system Model

(i) Information Providers

Are stakeholders who can upload data to the data collecting and dissemination system at any time. They are also rewarded or penalized based on their honest or dishonest respectively over a set length of time.

(ii) Information Users

Are stakeholders who can access information and provide input at any time through the information gathering and dissemination server. They are also rewarded or penalized based on their honest or dishonest respectively over a set length of time.

(iii) The Information Server and Incentive Server

Are the two main system components of the collection and dissemination server. The information server is in charge of keeping the uploaded data and disseminating the desired data to the users. During the entire system interaction, the incentive server is in charge of participation, reputation, incentive and penalty administration. The complete EPRIGM system model works as follows:

- When a user uploads data, the information saver saves it, and the incentive saver via participation component updates user participation correspondingly.
- The information saver disseminates the desired information whenever a user retrieves it, and the incentive saver via the participation update component modifies user participation correspondingly.
- When a user uploads feedback on retrieved information, the information saver preserves it; the incentive saver updates the information user's reputation and the designated information uploader's reputation via the reputation update component.
- After a set amount of time has passed, the model calculates user involvement and reputation score, judge users' honesty and dishonesty, calculates reward and penalty, and finally allocates it to the appropriate users.
- Finally, the model resets the user's participation and reputation scores before continuing the interaction circles.

3.13 Evolutionary Participation-Reputation Incentive Game Model

The user's reputation and participation score were computed using a sigmoid function in this investigation. The sigmoid function returns a result between zero and one. Sigmoid function, which has been frequently utilized, is more appropriate than other functions for modelling the concept of human behaviour (Ma *et al.,* 2016). Sigmoid function utilized in this study to capture the weighted aggregate number of logs and number of correct information or feedback published on system by an individual stakeholder for a time period t is defined by Equations (5) and (6).

$$r_{i,t} = \frac{2tan^{-1}(m_i)}{\pi}; \qquad 0 \leq r_{i,t} \leq 1 \qquad (5)$$

$$q_{i,t} = \frac{2tan^{-1}(n_i)}{\pi} \quad ; \qquad 0 \leq q_{i,t} \leq 1 \qquad (6)$$

Where:

m_i is the aggregated number of logs of an individual stakeholder for a period of time *t.*

n_i is the aggregated number of correct information or feedback of an individual stakeholder for a period of time *t.*

P= {p1, p2, p3, p4….pn} denotes the number of players (users) in the system model. Each player's (Users) strategy corresponds to Participating Honesty (H) and Participating Dishonestly (D). As a result, each player (User) will have the identical set of two strategies, honest and dishonest, symbolized by the letters S= {H, D}. This model's notations and symbols are defined in Table 8. The reputation score, indicated by $\boldsymbol{R_{i,t}}$ is a value between zero and one that may be calculated using the Equation (7).

$$R_{i,t}(q_{i,t}, r_{i,t}) = a * r_{i,t} * q_{i,t} * e^{b*e^{c*q_{i,t}*r_{i,t}}} \qquad (7)$$

The result $R_{i,t}$ of Equation (6) is the reputation score for an individual stakeholder *Pi* at time *t*, which ranges from zero to one. If $R_{i,t} \geq 0$, then the stakeholder is said to be honest, and if $R_{i,t} \leq 0$ and $q_{i,t} \geq 0$ then the stakeholder is dishonest. To make the decision easier, we utilize to symbolize μ whether user *Pi* is contributing honestly or dishonestly at moment *t.* As seen in Equation (8), we decided to reward honest users with incentives while appropriately punishing dishonest users.

$$\mu = \begin{cases} 1 \ ; Honest \\ -1 \ ; Dishonest \end{cases} \qquad (8)$$

Table 8: Definition of terms and notations

Symbol	Definition
Pi, Pj	Information providers and information users respectively
Ir	Incentive rate
Pr	Penalty rate
Ri,t	Users *Pi* reputation Score at time *t*
Rj,t	Providers *Pj* reputation Score at time *t*
Ui,t (x,y)	The expected Utility for user *Pi* at time *t* when information provider takes action *x* and information user takes action *y*
Uj,t (x,y)	The expected Utility for Provider *Pj* at time *t* when information provider takes action *x* and information user takes action *y*
m_i	Number of times user upload information or retrieve information
n_i	Number of useful information or truthful feedback user upload
$q_{i,t}$	Users Pi weighted accumulated historical system logs at time *t*
$q_{j,t}$	Providers Pj weighted accumulated historical system logs at time *t*
$r_{i,t}$	Users *Pi* weighted accumulated number of useful information or truthful feedback uploaded at time *t*
$r_{j,t}$	Providers *Pj* weighted accumulated number of useful information or truthful feedback uploaded at time *t*
F	Payable fees and taxes rate for a given time
A	Incentive Score at time *t*
K	Penalty Score at time *t*

Equations (9) and (10) yield the incentive score represented by A and the penalty score denoted by K of an individual shareholder participating honestly and dishonestly, respectively.

$$A = R_{i,t} * \mathrm{Ir} \tag{9}$$

$$K = q_{i,t} * \mathrm{Pr} \tag{10}$$

Both the information provider *Pi* and the information user *Pj* are supposed to be rational during the evolutionary game. As a result, under each strategy profile, we define the expected payout of information provider *Pi* and information user *Pj* as follows:

(i) When both information users and information providers adopt strategy honest (H) during their system interaction at time t, the payout for information provider Pi is Ui,t (H, H).

(ii) When the information user chooses the dishonesty approach, Ui,t (H, D) signifies the payment for the information provider Pi (D).

(iii) During their system interaction at time t, the information provider, on the other hand, chooses strategy honest (H).

(iv) During their system interaction at time t, Ui,t (D, H) signifies the reward for information provider Pi when the information user selects strategy Honest (H) and the information provider selects strategy Dishonest (D).

(v) When both information users and information providers choose strategy dishonest (D) during their system interaction at time t, Ui,t (D, D) signifies the reward for information provider Pi.

These payoffs for information provider *Pi* are summarized in Table 9.

Table 9: Payoff Matrix of Information Providers Pi

Information Provider P_i	**Information Users**		
		H	D
	H	$U_{i,t}$ (H,H)	$U_{i,t}$ (H,D)
	D	$U_{i,t}$ (D,H)	$U_{i,t}$ (D,D)

In each strategy profile, we defined the expected reward of information user *Pj* as follows:

(i) The payout for information user *Pj* is denoted by the *Uj,t (H, H).*

(ii) During system engagement at time *t*, both information users and information providers pick strategy honest *(H)*.

(iii) When the information user selects strategy honest *(H)* and the information provider selects strategy dishonest *(D)* during their system interaction at time *t*, *Uj,t (H, D)* signifies the reward for information user *Pj*.

(iv) During their system interaction at time *t*, *Uj,t (D, H)* signifies the reward for information user *Pj* when the information user chooses strategy dishonest *(D)* and the information provider chooses strategy honest *(H)*.

(v) When both the information user and the information provider choose strategy dishonest *(D)* during their system interaction at time *t*, *Uj,t (D, D)* signifies the reward for information user *Pj*.

These payoffs for information provider *Pj* are summarized in Table 10.

Table 10: Payoff Matrix of Information users Pj

Information user P_j	**Information Provider**		
		H	D
	H	$U_{j,t}$ (H,H)	$U_{j,t}$ (H,D)
	D	$U_{j,t}$ (D,H)	$U_{j,t}$ (D,D)

To ensure the system model's performance, users must be encouraged to participate honestly. Within the system model, the constraints specified by Equation (11) were defined to ensure that each user participates honestly.

$$\begin{cases} Ui,t(\mathrm{H,H}) > Ui,t(\mathrm{H,D}) \\ Ui,t(\mathrm{D,H}) > Ui,t(D,D) \\ Uj,t(\mathrm{H,H}) > Uj,t(\mathrm{H,D}) \\ Uj,t(\mathrm{D,H}) > Uj,t(\mathrm{D,D}) \end{cases} \tag{11}$$

After each play of the evolutionary game, the model adjusts the user's participation and reputation based on the user's strategy chosen during each iteration. After a defined period, *t*, the system calculates a participation and reputation score for each user, which is then used to determine the users' honesty or dishonesty. Whether the user participates honestly or dishonestly at time t is represented by μ in the judgment model. As a result, μ is set, as indicated by Equation (8), to reward honesty and punish dishonest users. As a result, Table 11 depicts the matrix of μ, which determines whether the user should be rewarded or penalized.

Table 11: Matrix of μ

Information Provider P_i	**Information Users *Pj***		
		H	D
	H	(1,1)	(1,-1)
	D	(-1,1)	(-1,-1)

In the strategy profile where both information providers and information users are honest at time *t*, Equations (12) and (13) characterize each player's expected incentive.

$$\{Ui, t(H, H) = F - R_{\boldsymbol{i},t} * Ir \tag{12}$$

$$\{Uj, t(H, H) = F - R_{\boldsymbol{j},t} * Ir \tag{13}$$

At time *t*, when information providers are honest and information users are dishonest, the expected incentive or penalty for each participant in the strategy profile defined by Equation (14) and (15).

$$\{Ui, t(H, D) = F - R_{\boldsymbol{i},t} * Ir \tag{14}$$

$$\{Uj, t(H, D) = F + q_{i,t} * Pr \tag{15}$$

When information providers are dishonest and information users are honest at time *t*, the predicted incentive or penalty for each participant in the strategy profile is defined by Equations (16) and (17).

$$\{Ui, t(D, H) = F + q_{i,t} * Pr \tag{16}$$

$$\{Uj, t(D, H) = F - R_{\boldsymbol{j},t} * Ir \tag{17}$$

When both information providers and information users are dishonest at time ***t***, Equations (18) and (19) define the predicted penalty for each actor in the strategy profile.

$$\{Ui, t(D, D) = F + q_{i,t} * Pr \tag{18}$$

$$\{Uj, t(D, D) = F + q_{j,t} * Pr \tag{19}$$

3.14 Replicator Dynamics

When players in an evolutionary game face a dynamic circumstance with ambiguous outcomes due to other players' strategies, they will change strategy in each tragedy and learn from pre-planned exchanges. The evolutionary stable strategy (ESS) is often used in evolutionary game theory as a steady equilibrium strategy perception. Under the stimulus of natural selection, ESS is a strategy that, if all members of the population adopt it, no distorted strategy can conquer the population. We used replicator dynamic equations to represent the trail of the distribution of strategies in the residents to investigate the evolution of participant strategies. We then agreed to transfer the practical ESSs if they met the conditions. Participants in our suggested paradigm are divided into two groups: information providers and information users. Because information providers may convert into information users in the next contact while the model is running, we assume that they will all pick the same honest strategy. We used *Ui's* utility function to model the strategy selection dynamics of information users, and *Uj's* utility function to describe the strategy selection dynamics of information providers.

3.14.1 Replicator Dynamics for Information Users

Researcher demarcated x_t as the ratio of stakeholders selecting the honest strategy at time t and ratio of them resulting dishonest strategy at time t as $1 - x_t$. Rendering to the game matrix, the payoff of information users selecting the honest strategy are given as:

$$P_u^H = x_t * U_{i,t}(H,H) + (1 - x_t) * U_{i,t}(H,D) \tag{20}$$

$$= x_t * \left(F - R_{i,t} * I_r\right) + (1 - x_t) * (F - R_{i,t} * I_r)$$

$$P_u^H = F - R_{i,t} * I_r \tag{21}$$

Then, the payoff of information users selecting dishonest strategy are given as:

$$P_u^D = x_t * U_{i,t}(D,H) + (1 - x_t) * U_{i,t}(D,D) \tag{22}$$

$$= x_t * \left(F + q_{i,t} * P_r\right) + (1 - x_t) * (F + q_{i,t} * P_r)$$

$$P_u^D = F + q_{i,t} * P_r \tag{23}$$

Thus, the average payoff of information users will be as follows:

$$P_u = x_t * P_u^H + (1 - x_t)P_u^D \tag{24}$$

$$= x_t * \left(F - R_{i,t}I_r\right) + (1 - x_t) * \left(F + q_{i,t}P_r\right)$$

$$P_u = -x_t\left(R_{i,t}I_r + q_{i,t}P_r\right) + (F + q_{i,t}P_r) \tag{25}$$

The replicator dynamic Equation of the proposed game for the information users can be formulated as follows:

$$\frac{dx_t}{dt} = x_t * (P_u - P_u^H) \tag{26}$$

$$= x_t * [\left(-x_t\left(R_{i,t}I_r + q_{i,t}P_r\right) + \left(F + q_{i,t}P_r\right)\right) - \left(F - R_{i,t}I_r\right)]$$

$$\frac{dx_t}{dt} = (x_t - x_t^2)(R_{i,t}I_r + q_{i,t}P_r) \tag{27}$$

The condition for ESS is that $\frac{dx_t}{dt} = 0$

$$x_t(1 - x_t)\left(R_{i,t}I_r + q_{i,t}P_r\right) = 0$$

The solutions are: $x_t = 0$ or $x_t = 1$

3.14.2 Replicator Dynamics for Information Providers

This study demarcated y_t as the ratio of stakeholders selecting the honest strategy at time t and ratio of them resulting dishonest strategy at time t as $1 - y_t$. Rendering to the game matrix, the payoff of information providers selecting the honest strategy are given as:

$$P_p^H = y_t * U_{j,t}(H,H) + (1 - y_t) * U_{j,t}(H,D) \tag{28}$$

$$= y_t * \left(F - R_{j,t} * I_r\right) + (1 - y_t) * (F - R_{j,t} * I_r)$$

$$P_p^H = F - R_{j,t} * I_r \tag{29}$$

Then, the payoff of information providers selecting dishonest strategy are given as:

$$P_p^D = y_t * U_{j,t}(D,H) + (1 - y_t) * U_{j,t}(D,D) \tag{30}$$

$$= y_t * \left(F + q_{j,t} * P_r\right) + (1 - y_t) * (F + q_{j,t} * P_r)$$

$$P_p^D = F + q_{j,t} * P_r \tag{31}$$

Thus, the average payoff of information providers will be as follows:

$$P_p = y_t * P_u^H + (1 - y_t)P_p^D \tag{32}$$

$$= y_t * \left(F - R_{j,t}I_r\right) + (1 - y_t) * \left(F + q_{j,t}P_r\right)$$

$$P_u = -y_t\left(R_{j,t}I_r + q_{j,t}P_r\right) + (F + q_{j,t}P_r) \tag{33}$$

The replicator dynamic equation of the proposed game for the information providers can be formulated as follows:

$$\frac{dy_t}{dt} = y_t * (P_p - P_p^H) \tag{34}$$

$$= y_t * [\left(-y_t\left(R_{j,t}I_r + q_{j,t}P_r\right) + \left(F + q_{j,t}P_r\right)\right) - \left(F - R_{j,t}I_r\right)]$$

$$\frac{dy_t}{dt} = (y_t - y_t^2)(R_{j,t}I_r + q_{j,t}P_r) \quad (35)$$

The condition for ESS is that $\frac{dy_t}{dt} = 0$

$$y_t(1 - y_t)(R_{j,t}I_r + q_{j,t}P_r) = 0$$

The solutions are $y_t = 0$ or $y_t = 1$

3.15 Evolutionary stable strategy (ESS) analysis

Zhu *et al.* (2010) defined evolutionary stable strategy as the set of fixed points of the system of differential equations that are stable. However not necessarily that all the two solutions obtained in (26) and (34) are all ESSs for the evolutionary game for information users and information providers respectively. Thus we analyzed the evolutionary stable strategies (ESSs) for both information users and information providers through the proposed evolutionary participation reputation based game model according to the conditions which governs the ESS.

3.15.1 Analysis for Information Users Stability

A strategy x_t is the ESS if and only if it satisfies two conditions namely, equilibrium and stability. That means H(x) should satisfy the following conditions:

$$\begin{cases} H(x_t) = 0 \\ H'(x_t) < 0 \end{cases} \quad (36)$$

From the replicator dynamics analysis for the information users, all the two solutions $x_t = 0$ and $x_t = 1$ satisfies the first condition $H(x_t) = 0$. We then determined and eliminated the solutions which did not satisfy the second condition $H(x_t) < 0$ to remain with a unique ESS.

Let $H(x_t) = \frac{dx_t}{dt}$; Thus from (26) we get:

$$H(x_t) = (x_t - x_t^2)(R_{i,t}I_r + q_{i,t}P_r)$$
$$H'(x_t) = (1 - 2x_t)(R_{i,t}I_r + q_{i,t}P_r)$$

Thus, $H'(x_t = 1) = -(R_{i,t}I_r + q_{i,t}P_r)$ (37)

$$H'(x_t = 0) = (R_{i,t}I_r + q_{i,t}P_r) \quad (38)$$

Therefore, $H'(x_t = 0) > 0$ and $H'(x_t = 1) < 0$

Only $x_t = 1$ satisfy the second condition and is the only ESS in the evolutionary game for information users. This analysis result portray that all information users will choose honest strategy at the end of the evolutionary game and reach the evolutionary stable state. This indicate that regardless of the population of information users selecting "honest" or "dishonest" at the beginning of the game, after a time of evolution, all the information users will select the clean strategy (honest). Therefore, EPRIGM can ensure trustworthy of information users in cloud collection and dissemination of fisheries information.

3.15.2 Stability Analysis for Information Providers

A strategy y_t is the ESS if and only if it satisfies two conditions namely, equilibrium and stability. That means H(y) should satisfy the following conditions:

$$\begin{cases} H(y_t) = 0 \\ H'(y_t) < 0 \end{cases} \tag{39}$$

From the replicator dynamics analysis for the information providers, all the two solutions $y_t = 0$ and $y_t = 1$ satisfies the first condition $H(y_t) = 0$. We then determined and eliminated the solutions which did not satisfy the second condition $H(y_t) < 0$ to remain with a unique ESS.

Let $H(y_t) = \frac{dy_t}{dt}$; Thus from (34) we get:

$$H(y_t) = (y_t - y_t^2)(R_{j,t}I_r + q_{j,t}P_r)$$

$$H'(y_t) = (1 - 2y_t)\left(R_{j,t}I_r + q_{j,t}P_r\right)$$

Thus: $$H'(y_t = 1) = -\left(R_{j,t}I_r + q_{j,t}P_r\right) \tag{40}$$

$$H'(y_t = 0) = (R_{j,t}I_r + q_{j,t}P_r) \tag{41}$$

Therefore, $H'(y_t = 0) > 0$ and $H'(y_t = 1) < 0$

Only $y_t = 1$ fulfil the second condition and is the only ESS in the evolutionary game for information providers. This stability analysis for information providers depict that no matter whether the population of information users select honest or dishonest at the beginning of the game, after time of evolution, all the information providers will choose the honest strategy.

Therefore, the anticipated participation-reputation based incentive mechanism can ensure information providers donate accurate information to promise the performance of the system.

3.16 EPRIGM Model Coding and Experimental Simulation

The model was coded and performed series of experiment using MATLAB software. The experimental results validated that our adopted incentive mechanism can encourage stakeholders to select honest strategy. If stakeholders choose dishonest strategy, they will be punished immediately and this will discourage the choice of dishonest strategy again. Our experimental results presents the dynamic of the proportion of honesty ($x_t$and y_t) and reputation scores ($R_{i,t}$ and $R_{j,t}$) for information users and information providers, respectively. We further analyzed the consequence of initialized values of the honest proportion (x_0 and y_0) on the time to reach ESSs. To achieve satisfiable results, parameters a, b and c must be set between 0.1 and 0.9. The following setup: $x_0 = 0.7, y_0 = 0.7, a = 0.9, b = 0.6, c = 0.9, I_r = 0.6$, $P_r = 0.3$, and $F = 100$ was used in simulation experiment.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Strength and Weakness of the Existing Mechanism for Collection and Dissemination of Fisheries Information

(i) Overview on the Percentage Achieved by the Research Tools Used

There are various channels currently used by fisheries stakeholders in accessing, gathering and disseminating information. These channels include questionnaire, interview, seminar, compact disc (CD), DVD, telephone or mobile phone calls, television, radio and internet.

Interview, questionnaire, and seminar are interactive communications, easy to understand and are individual services. The weakness of these channels is that it requires human involvement, time consuming, less efficient and more expensive. Study results indicated that level of Interview, questionnaire, and seminar as a means of accessing, collecting and disseminating information is low among fisheries stakeholders. Only 44 (11.4%) respondents gather fisheries information using questionnaire, 44 (11.4%) gather fisheries information using interview, 40 (10.5%) gather fisheries information using seminar.

Compact disc (CD) and DVD are easy to understand, can be saved for future references. However, it requires human involvement, can be time consuming and less efficient, costs are high due to the requirement of a player device. Results indicated that few 10 (2.7%) respondents gather or disseminate information using CD and DVD.

Radio and television can convey fisheries information to an extremely huge number of stakeholders across the length and broadness of a specific geographic at low cost. However, it is not interactive, does not provide tailored information to all stakeholders, unfavourable radio/television broadcasting time, it requires access to a receiver which may be challenge to some stakeholders. Study results indicated that only 9 (2.3%) of the respondents gather or disseminate fisheries information using radio and television.

Telephone or mobile phone calls are Interactive communications, easy to understand and individual service. Conversely, it requires human involvement, time consuming and less efficient and more expensive. Survey result indicated that no respondent gather or disseminate fisheries information using landline phone or mobile phone call.

(ii) Response Rate

The researcher administered data collection by distributing (450) questionnaires to stakeholders from the Ministry of Livestock and Fisheries Development (MLFD), Mwanza and Mara regions. Managed to collect back (400) questionnaires from respondents, providing response rate of (88.8%). The response rate above (80%) is sufficient for a study as suggested by Mugenda and Mugenda (2003). The data obtained from these respondents and literature review was sufficient to answer research questions of this study. The Table 12 and 13 summarizes the study response rate and collected data respectively.

Table 12: Response rate

S/no	Categories	Frequency	Percentage
1	Collected back	400	88.8
2	Not Collected back	50	11.2
	Total	**450**	**100**

Table 13: Summarized collected data

	FS_ROLE	*FS_EDUC_LEVEL*	*FS_AGE_RANGE*	*FS_MOB_OWN*	*FS_MOB_TYPE*	*FS_EXPERIENCE*
count	384	384	384	384	384	384
unique	3	5	3	2	4	5
top	Fisher man	Primary_ Education	Between 19-45_ years_old	Yes	Featured_Mobile_Phone	Between_21 - 30_years
frequency	200	282	346	359	226	247

Gender

In order to determine the respondent gender, the questionnaire asked the respondent to indicate their gender. The study revealed that the majority of the respondent were male 323 (83.9%) response rate compared to female 62 (16.1%). This results revealed low participation of women in fisheries subsector compared to men counterpart. Figure 8 shows this analysis of gender.

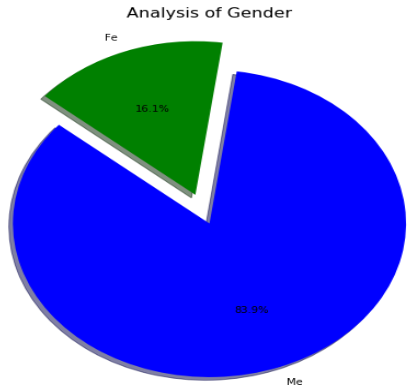


Figure 8: Analysis of Gender

Age Range

Age range analysis results show that majority of the respondents 350 (91%) were ranging from 19-45 years, 32 (8.3%) respondents were ranging from 46-60 years and only 3 (0.7%) respondent were above 60 years old. No respondent were below 18 years old as depicted in Fig. 9. This shows that below 18 years old are not involved in fisheries because majority of them are still attending schools. It also shows that youth are the mostly involved with fisheries activities compared to the old age groups.

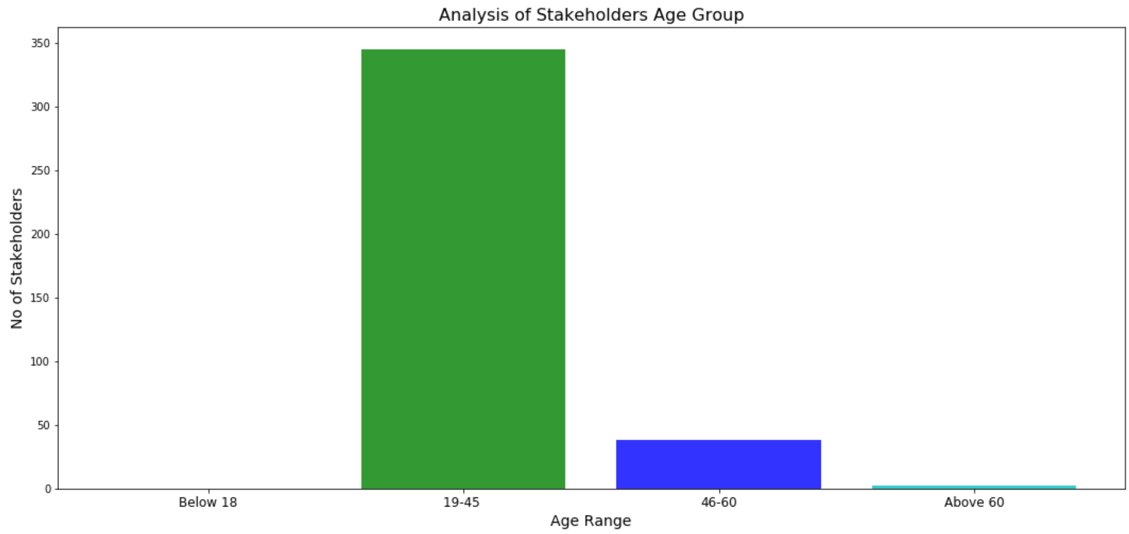


Figure 9: Respondent age range

(iii) Educational Level

The study intended to understand the education level of the respondents. Results revealed that majority of the stakeholders 280 (72.7%) education level were primary school, followed by secondary education 75 (19.5%), degree or above 20 (5.2%) and only few 10 (2.6%) were having diploma as shown in Fig. 10. The findings revealed that most fisheries stakeholders have at least primary education and are capable of reading and understand information disseminated to them through various channels.

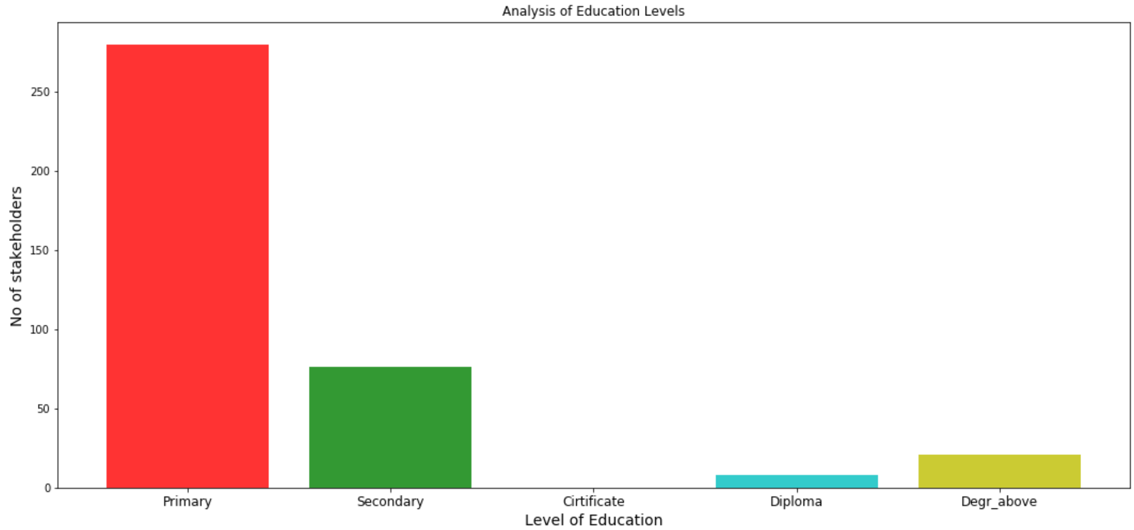


Figure 10: Respondent level of education

(iv) Respondent Working Experience in Fisheries Sector

The study necessitated the respondent to indicate their working experience in fisheries sector and Fig. 11 represents the findings. From findings, the majority of the respondent 230 (59.7%) their experience ranges from 21-30 years, 120 (31.2%) of the respondent, their experience ranges from 11-20 years, 25 (6.5%) of the respondent, their experience ranges from 5-10 years. Furthermore, study revealed that 6 (1.6%) of the respondent their experience are below 5 years, 4 (1.0%) of the respondent their experience was ranging from 31-40 years and no respondent was having experience above 40 years. This shows that few young generations are entering in this sector and the older stakeholders are quitting due to old age.

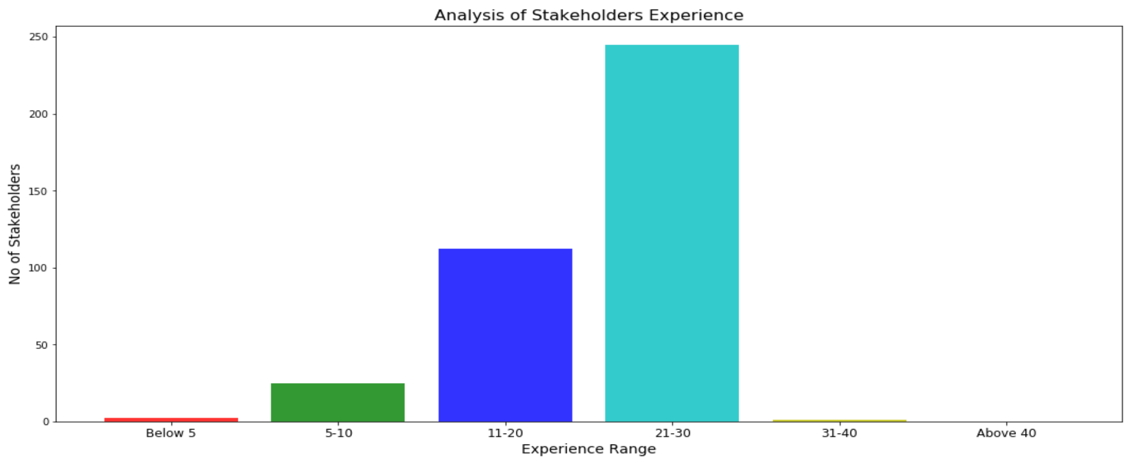


Figure 11: Respondent fisheries working experience

(v) Respondent Type of Species Trading or Fishing

The study sought to determine the type of species respondents are trading or fishing and Fig. 12 depicts the findings. Finding discovered that 143 (37.1%) of the respondent's trawl or trade Nileperch, 140 (36.3%) trade or fish sardine (dagaa), 81 (21.1%) are trading or trawl Tilapia and 21 (5.5%) are not trading or trawling. These results shows that Nileperch and Dagaa are the most traded or trawled species by most stakeholders.

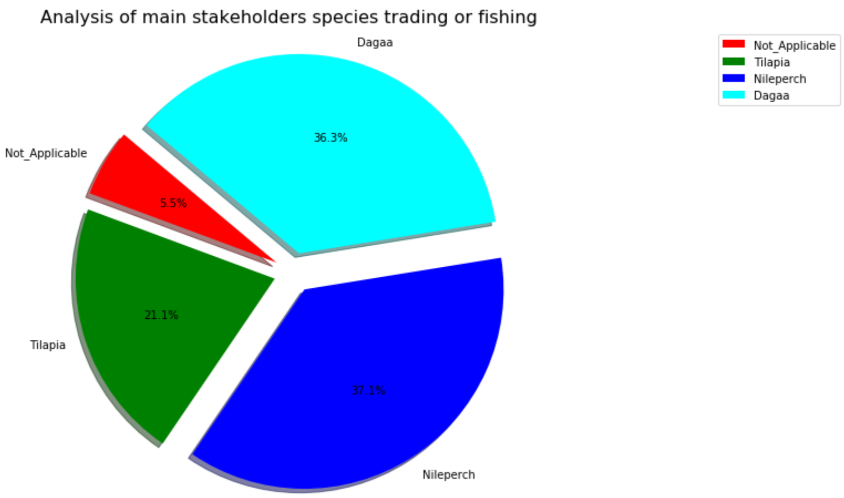


Figure 12: Analysis of stakeholder's species trading or fishing

(vi) Respondent Role in Fisheries Sector

The study sought to determine the role of respondents within the fisheries sector. The findings show that 200 (51.9%) of the respondents were fisherman, 160 (41.6%) was traders and 25 (6.5%) was fisheries officers. Findings indicated that traders and fisherman were the majority fisheries stakeholder's groups. Figure 13 depicts the findings.

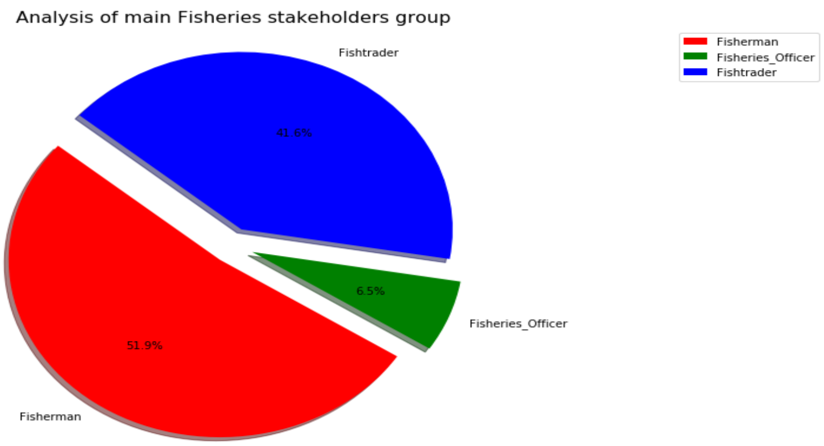


Figure 13: Analysis of main stakeholder's role

(vii) Fisheries Stakeholders' Involvement in Information Gathering

The study requested respondent to indicate if they have been involved in fisheries information gathering before. This study revealed that majority of respondents 325 (84.4%) have not been involved in fisheries information collection and only 60 (15.6%) has been involved as depicted in Fig. 14. This finding indicate that participation of stakeholders in fisheries data collection are not sufficient.

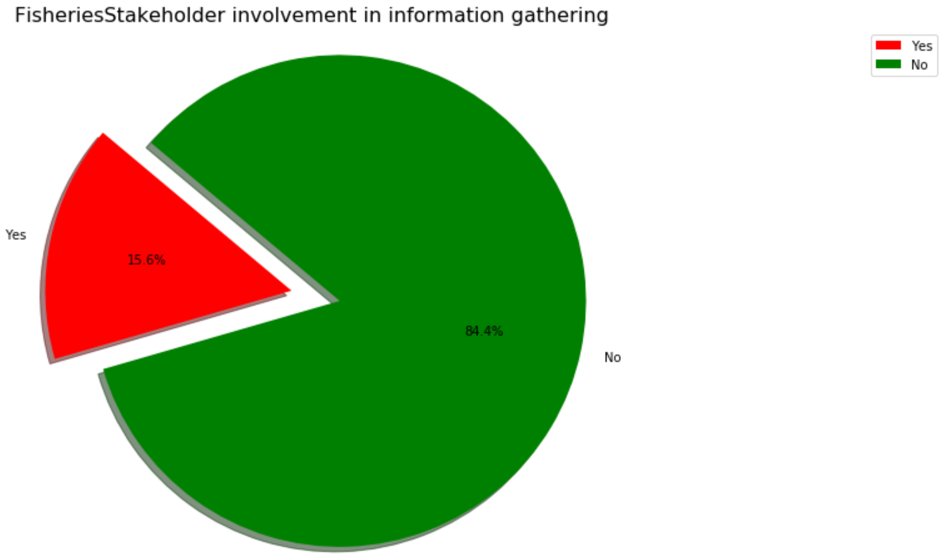


Figure 14: Analysis of stakeholder's involvement in information gathering

(viii) Fisheries Information Gathering and Dissemination Mode

The study requested respondents to state how they disseminate fisheries information to their stakeholders. Findings indicated that majority of respondents 238 (61.7%) are informally. Further results indicated that 44 (11.4%) respondents gather fisheries information using questionnaire, 44 (11.4%) gather fisheries information using interview, 40 (10.5%) disseminate fisheries information using seminar, 10 (2.7%) disseminate fisheries information using CD and DVD, 9 (2.3%) disseminate fisheries information using radio and television, and no respondent indicated using landline phone, mobile phone or internet. Figure 15 presents these results.

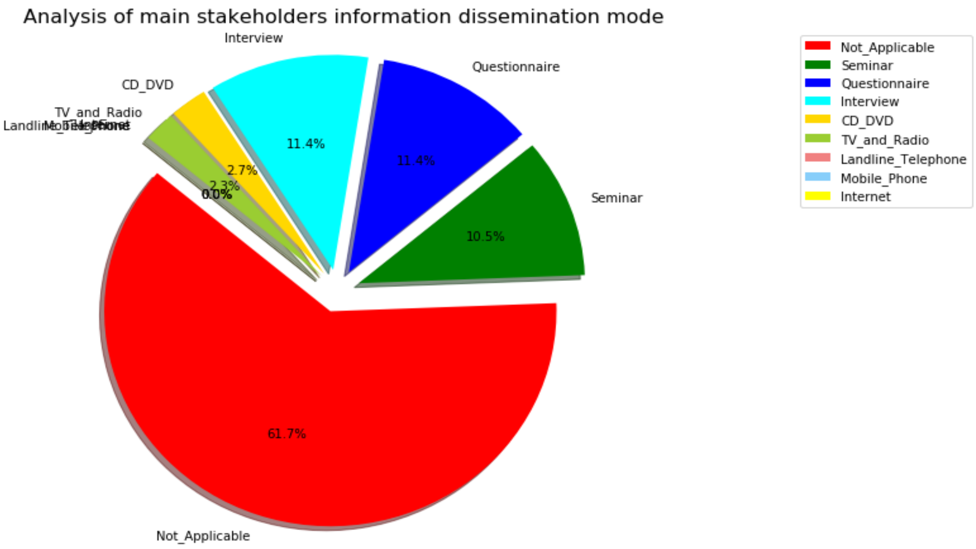


Figure 15: Analysis of fisheries information dissemination mode

(ix) Stakeholders Radio Access

The study requested respondents to state if they have radio access. Results shows that majority respondent 228 (59.2%) have access with radio and 157 (40.8%) respondents do not have access with radio. This finding revealed that more than 50% of fisheries stakeholders have radio access. Figure 16 summarizes these results.

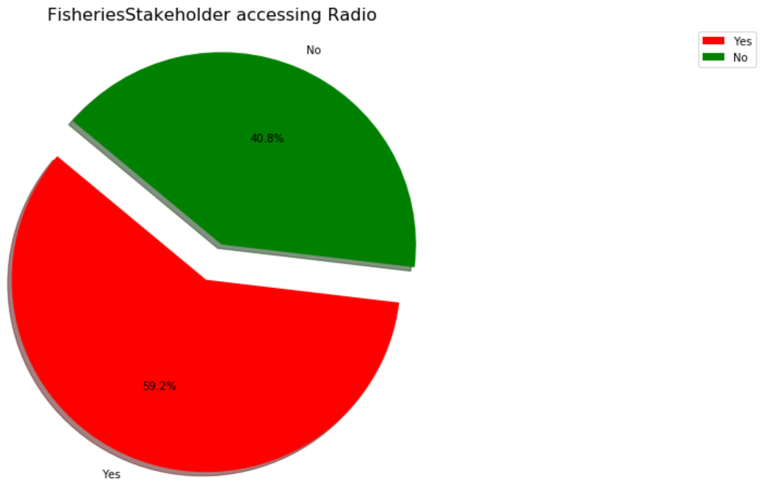


Figure 16: Analysis of stakeholders Radio access

(x) Stakeholder Listening Fisheries Radio Program

The study requested respondent to state if they listen fisheries program from radio. Findings indicated that majority of respondents 340 (88.3%) are not listening fisheries program from radio, and only 35 (11.7%) are listening fisheries programs from radio. This result is contrary to other studies that revealed that more than 50% of fishers listen to radio programs (Schubert *et al.*, 2022; Kamau *et al.*, 2021; Consolata, 2017). Figure 17 summarizes these results.

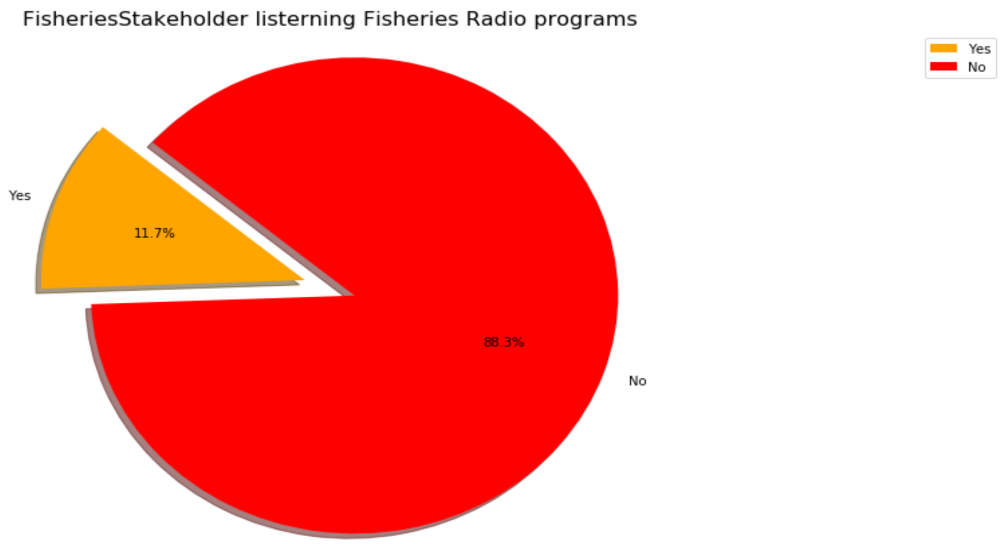


Figure 17: Analysis of stakeholders listening fisheries radio program

(xi) Stakeholders Television Access

The study sought to understand the respondent television access status and Fig. 18 summarizes these results. Findings revealed that 212 (55%) respondents do not have television access and 173 (45%) have television access.

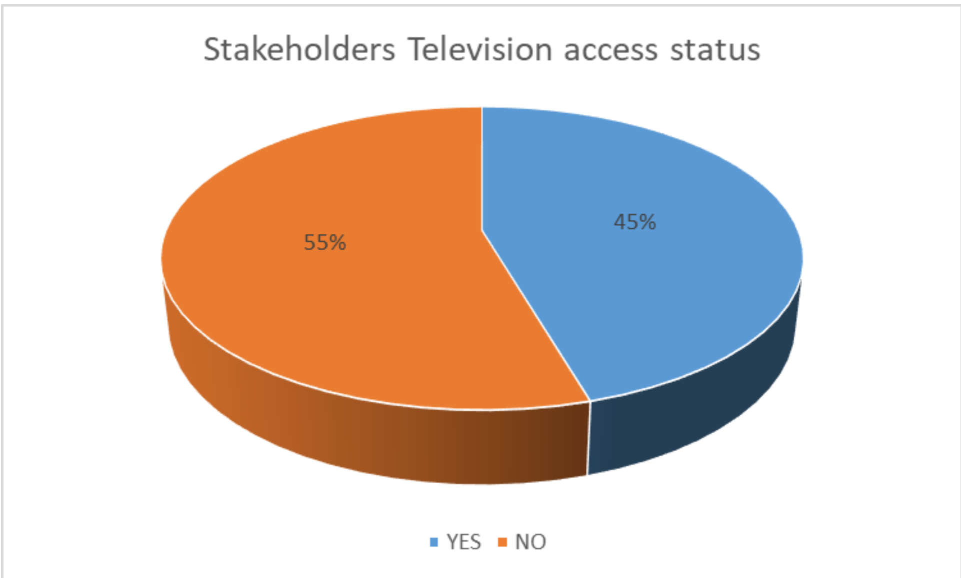


Figure 18: Analysis of stakeholder's television access status

(xii) Stakeholders Watching Fisheries Program on Television

The study requested respondents to state if they watch fisheries program on television. Results shows that majority of respondents 382 (99.2%) do not watch fisheries programs on television and only 3 (0.8%) respondents watch fisheries programs on television as indicated by Fig. 19. Our result is contrary to other studies which revealed that more than 50% of fishers' watch television programs about fisheries (Benard *et al.*, 2020; Obiero *et al.*, 2019; Schubert *et al.*, 2022).

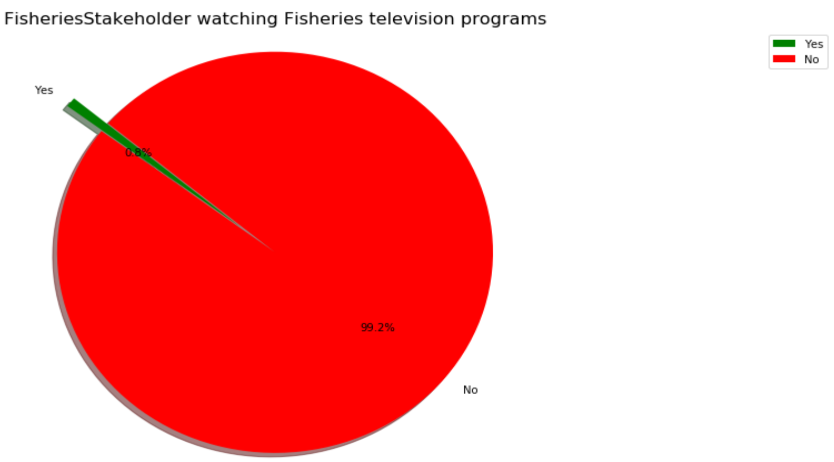


Figure 19: Analysis of stakeholders watching fisheries programs on television

(xiii) Stakeholders Computer Access

The study asked respondents to indicate if they have computer access. Results revealed that majority of respondents 350 (91%) do not have computer access and 35 (9%) have computer access as presented in Fig. 20. Findings shows that majority of fisheries stakeholders have limited computer access and thus it is not effective tool in gathering and disseminating fisheries information.

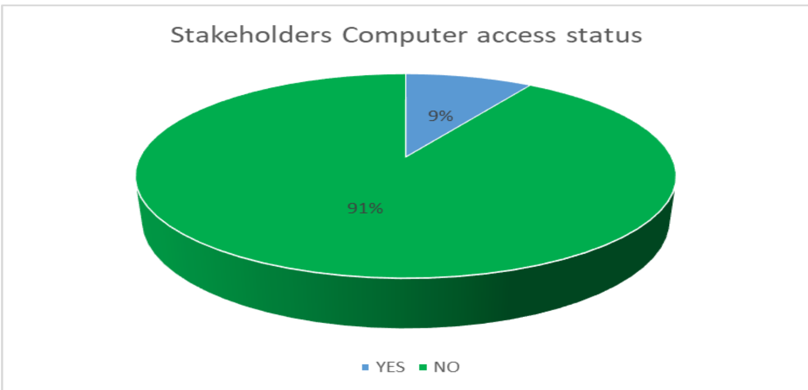


Figure 20: Analysis of stakeholder's computer access

(xiv) Stakeholders Accessing Fisheries Information through Computer

The respondent was requested to indicate if they are accessing fisheries information through computer and results are presented by Fig. 21. Findings revealed that majority of the respondent 372 (96.6%) do not access fisheries information using computer and only 13 (3.4%) do access fisheries information through computer. This finding indicate that fisheries stakeholders are limited in accessing fisheries information using computer.

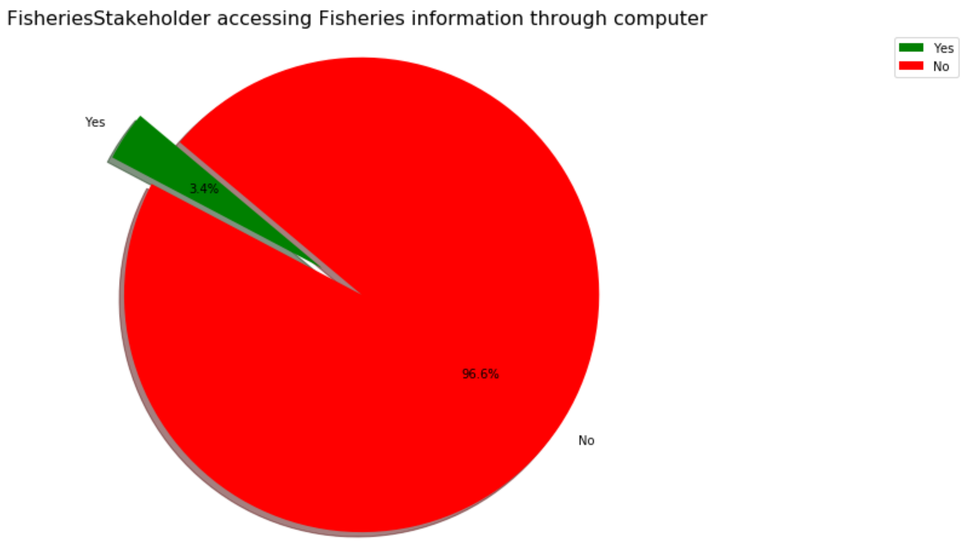
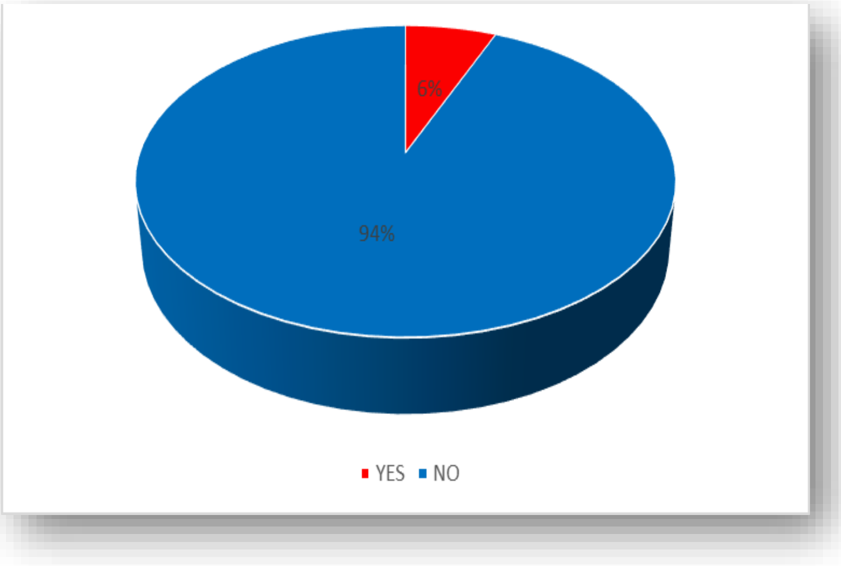


Figure 21: Analysis of stakeholders accessing information through computer

(xv) Stakeholders PDA Access

Response shows that majority of respondents 362 (94%) do not have access to Portable Digital Accessories (PDA) and only 23 (6%) of respondent has access to PDA as depicted in Fig. 22. This finding indicate that PDA are not convenient ICT tools for fisheries information gathering and dissemination to the majority stakeholders.



(xvi) Stakeholders Accessing Information through Portable Digital Accessories

Figure 23 presents the response showing that majority of respondents 384 (99.7%) do not access fisheries information through Portable Digital Accessories (PDA) and only 1 (0.3%) of respondent access fisheries information through PDA. This finding also indicate that PDA are not convenient ICT tools for fisheries information gathering and dissemination to the majority stakeholders.

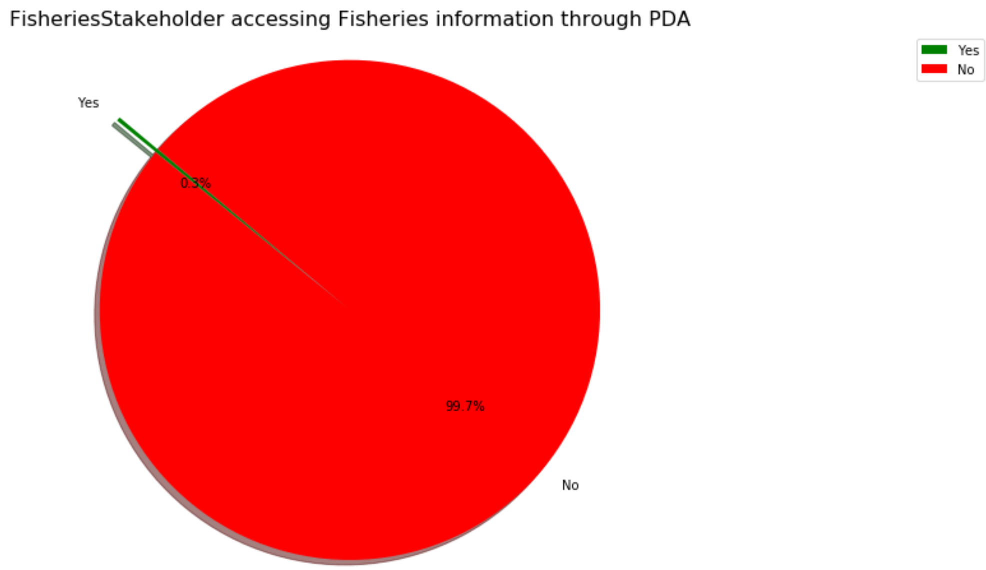


Figure 22: Analysis of stakeholders accessing information through PDA

(xvii) Stakeholders Mobile Phone Ownership

Study results indicated that majority of respondents 356 (92.5%) own mobile phone and 29 (7.5%) of respondents do not own mobile phone. This finding indicate that mobile phone can be convenient ICT tool for fisheries information gathering and dissemination to stakeholders since majority do own it. These results are presented in Fig. 24.

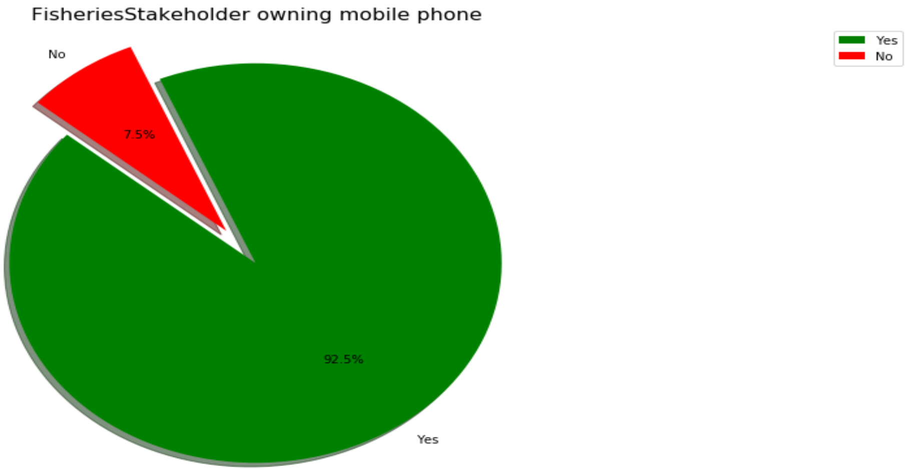


Figure 23: Analysis of stakeholder's mobile phone ownership

(xviii) Stakeholders Mobile Phone Type Ownership

Response indicated that 252 (65.4%) respondents own featured mobile phone and 133 (34.6%) respondents own smart mobile phone as depicted in Fig. 25. This finding indicate that featured mobile phone are more convenient for fisheries information gathering and dissemination compared to smart mobile phone.

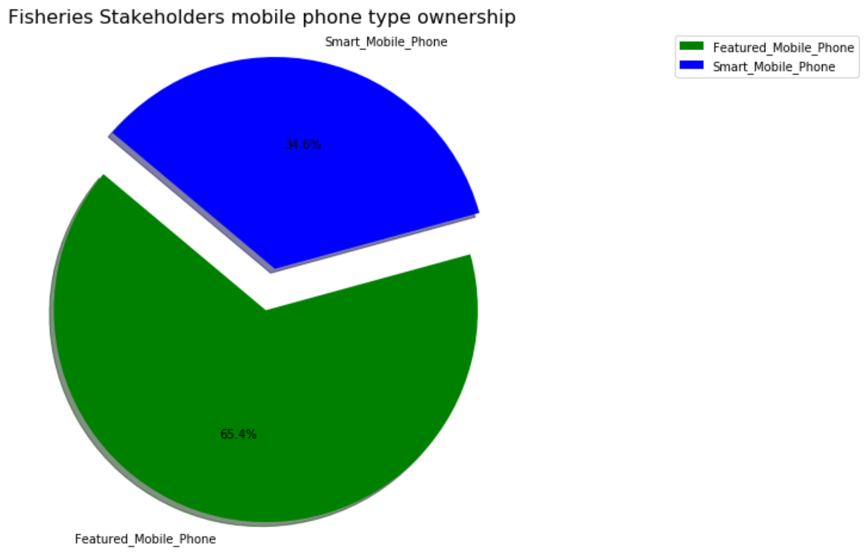


Figure 24: Analysis of stakeholder's mobile phone type

(xix) Stakeholders Accessing Information through Mobile Phone

The study sought to understand if currently respondent do access fisheries information through mobile phone. Response indicated that currently none (0.0%) of the respondent access fisheries information through mobile phone as depicted in Fig. 26.

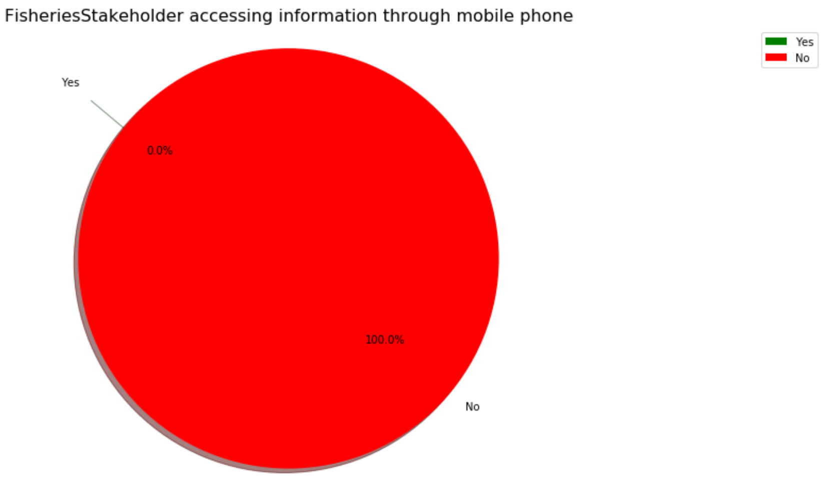


Figure 25: Analysis of stakeholders accessing information through mobile phone

(xx) Stakeholders Information Sharing

The study requested respondents to indicate if they do share fisheries information with their fellows. Results shows that majority of respondents 376 (97.7%) do share fisheries information with their fellows and only 9 (2.7%) of respondents do not share fisheries information with their fellows. This finding indicates that majority of fisheries stakeholders do share received fisheries information with their local fisheries stakeholders as shown in Fig. 27.

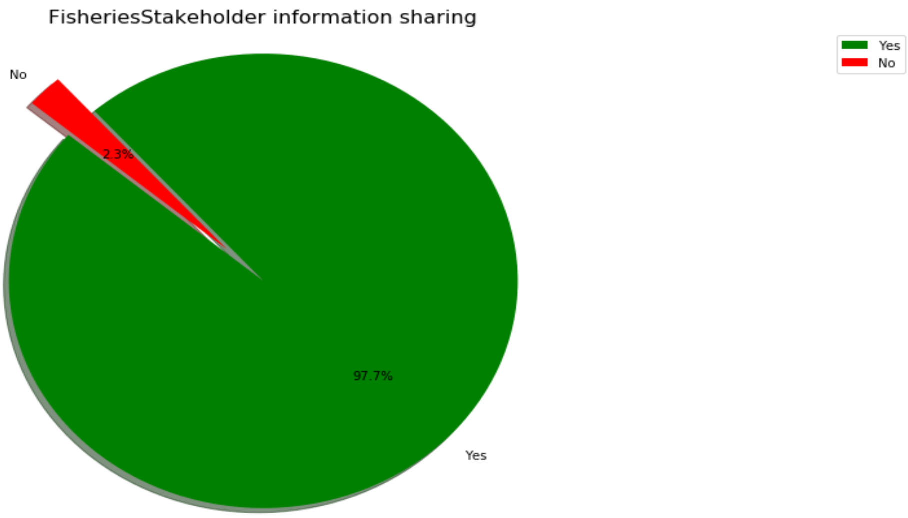


Figure 26: Analysis of stakeholder's information sharing

(xxi) Stakeholder Information Sharing Mode

The researcher intended to understand how respondents share fisheries information with their fellow stakeholders. Response indicated that 166 (43.1%) uses physical visit to share information, 164 (42.6%) uses mobile phone to share information, 49 (12.8%) uses WhatsApp application to share information and 6 (1.5%) uses internet to share information as depicted in Fig. 28. This result indicates that physical visit and mobile phone are the most used means of sharing fisheries information. However, physical visit is tedious, consumes time and are not efficient.

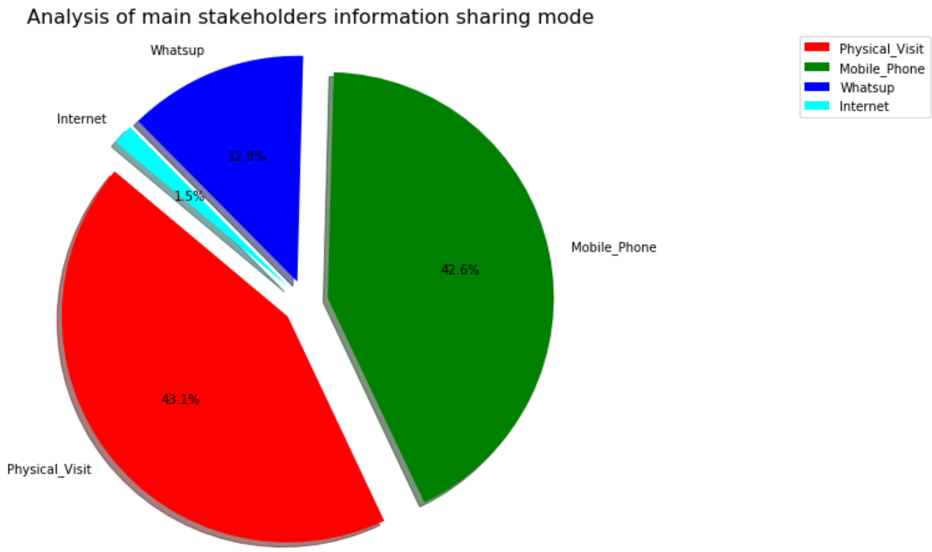


Figure 27: Analysis of stakeholder's information sharing mode

(xxii) Stakeholders Required Information

The study sought to understand the type of information required by respondent in order to improve their occupation in the fisheries sector. Response indicated that 68 (17.7%) respondents requires policy and guidelines information, 66 (17.1%) respondents requires financial credit information, 65 (17%) respondents requires market price information. Furthermore, study indicated that 42 (10.7%) respondents requires best fishing practice information, 41 (10.7%) respondents requires fishing gears information, 37 (9.5%) respondents requires security measures information, 37 (9.5%) respondents requires weather forecast information and 30 (7.7%) respondents requires transportation information as potrayed in Fig. 29. Findings revealed that best fishing practice, fishing gears, market price, financial credit, policy and guidelines, weather forecast, security measures and transport are the mostly required information by fisheries stakeholders.

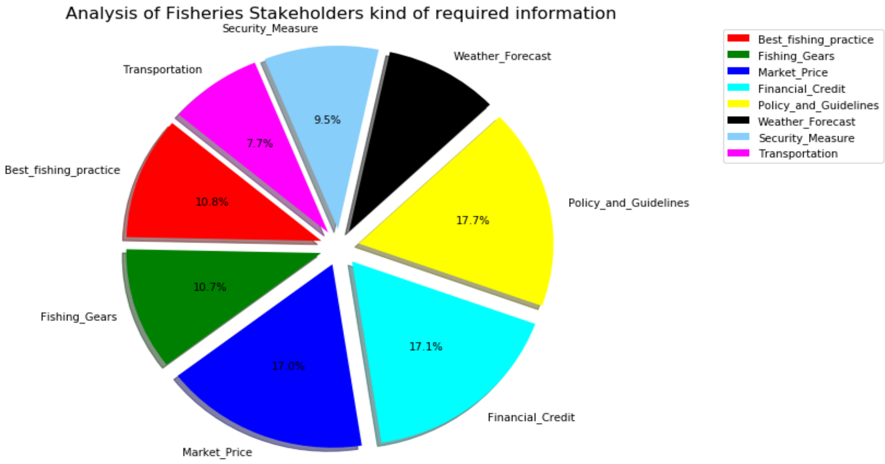


Figure 28: Analysis of stakeholders required information

(xxiii) Stakeholders Information Format Required

The study requested respondents to state their preferred fisheries information format and Fig. 30 depicts the results. Response indicated that 171 (44.5%) respondents prefer to receive fisheries information in text format, 155 (40.3%) respondents prefer to receive fisheries information in audio format, 48 (12.5%) respondents prefer to receive fisheries information in image format, and 11 (2.7%) respondent prefer to receive fisheries information in video format. This finding revealed that text, audio, image and video are the mostly preferred information format by fisheries stakeholders.

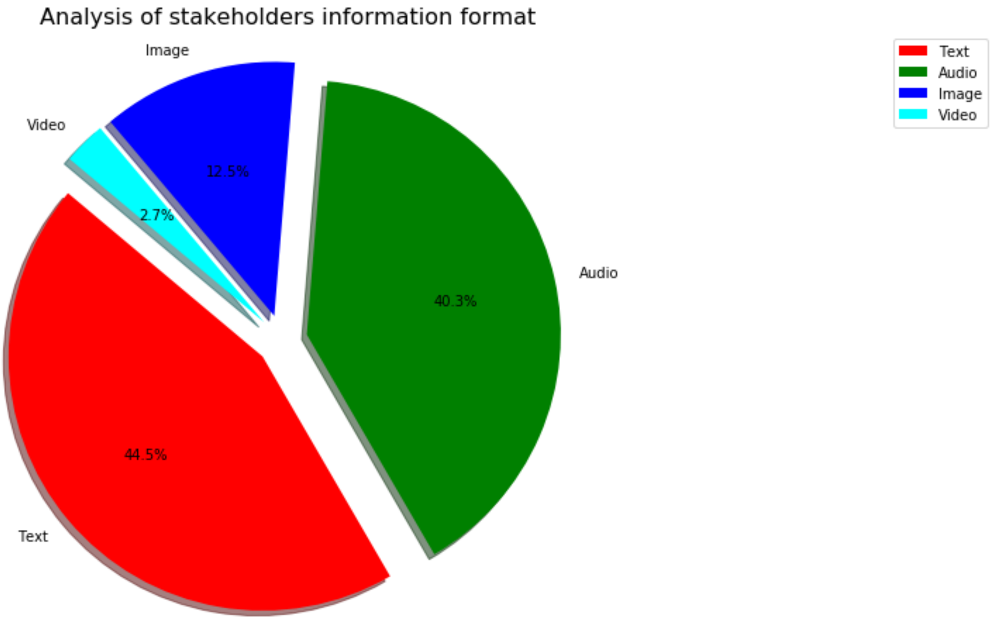


Figure 29: Analysis of stakeholder's information format required

(xxiv) Stakeholders Information Access Frequency

The study also requested respondent to indicate their preferred information access frequency. Response shows that majority respondents 275 (71.4%) preferred to access fisheries information on demand bases, 54 (14.1%) respondents preferred to access fisheries information monthly, 35 (9.1%) respondents preferred to access fisheries information weekly, 14 (3.6%) respondents preferred to access fisheries information daily, and 7 (1.8%) respondent preferred to access fisheries information annually as depicted in Fig. 31. Findings revealed that on demand, monthly and daily are the mostly required information frequency access by fisheries stakeholders.

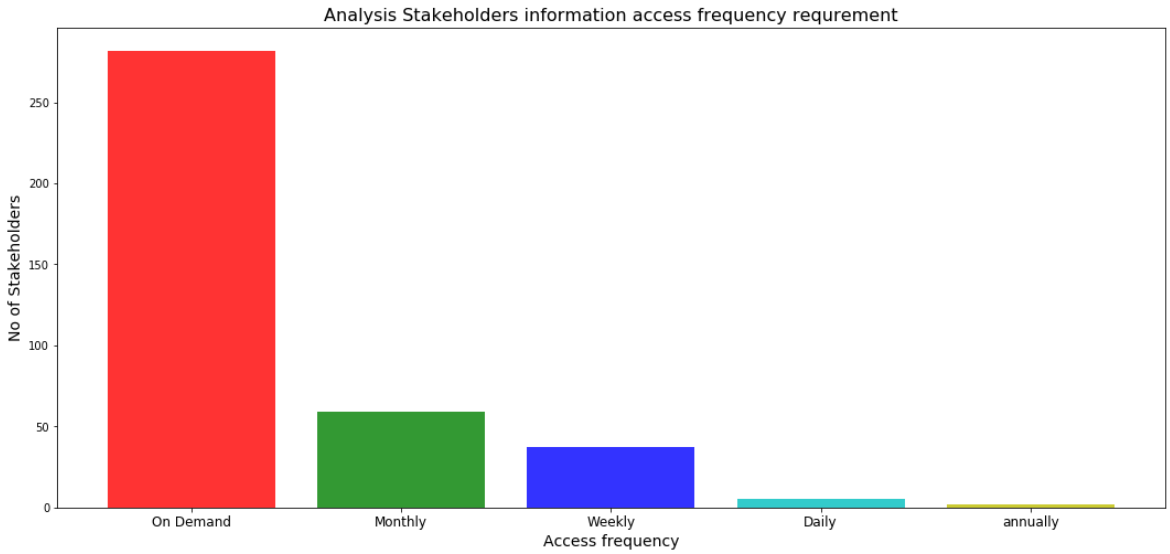


Figure 30: Analysis of stakeholder's information access frequency

(xxv) Comprehensive Comparison of the Six Channels Effectiveness Probability

Comprehensive comparison of the six channels effectiveness probability results revealed that different channels have different information dissemination effectiveness for various fisheries stakeholders as depicted in Fig. 32. Television and radio have zero effective dissemination probability for both fisherman, fish traders, and fisheries officers. The reasonable number of respondents 340 (88.3%) who do not listen to fisheries programs via radio or watch fisheries programs on television due to various reasons contributed to the zero effective dissemination probability. Some of these reasons include lack of television and radio access, programs timing challenge, and non-tailored fisheries program availability. This result is contrary to other studies which revealed that more than 50% of fishers listen to the radio and watch television programmes about fisheries (Basavakumar *et al.,* 2011; Omar & Chhachhar, 2012; Philip &

Udoh, 2011). The cellular phone call, SMS and USSD are most useful to fishers, followed closely by fisheries officers and fish traders. The mobile phone call, SMS and USSD have an essential role in gathering and disseminating fisheries information because they feature higher information dissemination effectiveness for both stakeholders. This efficiency was aided by the fact that 356 (92.5%) of respondents owned a featured mobile phone. Other research has found that fishers use mobile phones to interact with friends and associated agencies in order to obtain information (Omar & Chhachhar, 2012; Salia *et al.*, 2011; Zobidah *et al.*, 2011). These findings attest that Cellular phone call, SMS and USSD are a useful channel to both stakeholders. However, the cellular phone call is costly compared to SMS and USSD and maybe challenge to fishers. The mobile application has a significant role in gathering and disseminating fisheries information because they feature higher information dissemination effectiveness for fisheries officers and fish traders. These stakeholder groups can best use the channel because most of them own smart mobile phones capable of running mobile applications. The website is only most effective for fisheries officers and less useful to fish traders. These stakeholder groups (fisheries officers and fish traders) can use the website channel because they have access to internet services.

Figure 31: Comprehensive comparison of the six channels effectiveness probability

4.1.2 Evolutionary Participation-Reputation Incentive Game Model Simulation Experimental Results

(i) The Dynamics Evolution for Information Users

When $x_0 = 0.7$, the dynamic evolutions of x_t and $R_{i,t}$ for information users are depicted in Fig. 33. The simulation results in Fig. 33 demonstrates that x_t will rise until it reaches the steady state. At the beginning of the game, information users choose the honest strategy and their reputations grows with their choices. However, if due to any reasons an information users choose dishonest strategy, their reputations will decline and will be penalized immediately as described in Fig. 33. Then the penalized information users after some time *t* will note that their fees and taxes amount has increased compared to the originally set fees and taxes. Therefore, next iteration they will try to choose honest strategy and observe the results. When compared to the fees and taxes that were originally set, the information users will notice lower costs and taxes during this iteration. As a result, information users will choose an honest strategy to save money on fees and taxes. Finally, users of information will only choose honest strategies, and the fraction of honest users will stabilize. The outcome of our simulation shows that information users learn from the payoff they obtain for each strategy they choose during a game round and alter strategies to optimize their payoffs (discount).

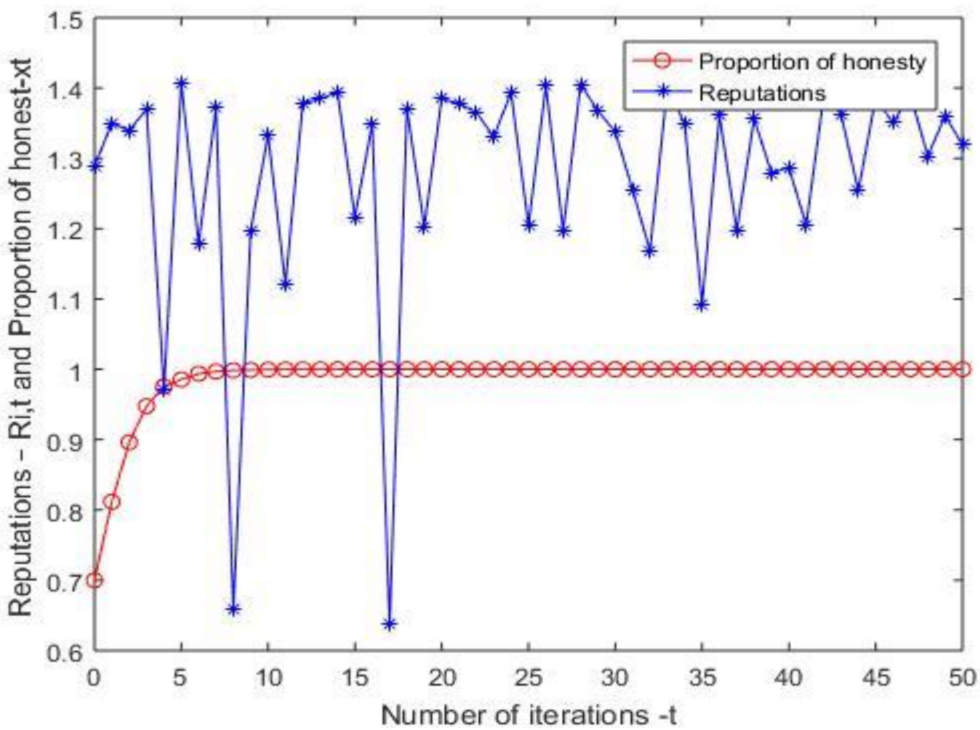


Figure 32: The evolution of x_t and $R_{i,t}$ for initialized value $x_0 = 0.7$

The effect of initialization values of the honest proportion x_0 on information users is seen in Fig. 34. As seen in Fig. 34, the higher the number of honest individuals at the start of the evolutionary game, the faster the group ESS grows. The key reason is that if a larger percentage of information users pick honest strategy, the remaining information users who choose dishonest approach have a high possibility of switching to honest strategy as the game progresses. As a result, dishonest information users will have a high possibility of switching to a more honest technique in order to receive more reductions on fees and taxes. As a result, information providers will quickly alter their techniques in order to achieve a more stable condition.

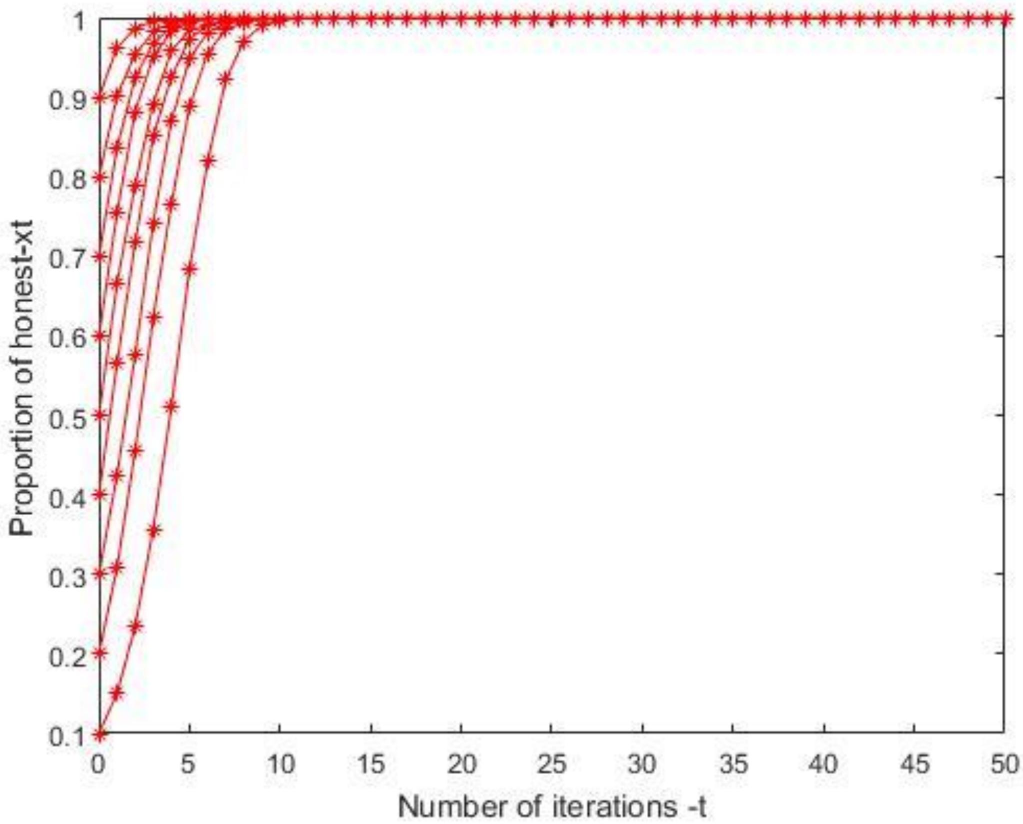


Figure 33: The effect of initialized value x_0 on information users

(ii) The Dynamics Evolution for Information Providers

When $y_0 = 0.7$, the dynamic evolutions of y_t and $R_{j,t}$ for information providers are portrayed in Fig. 35. The simulation results in Fig. 35 exhibits that y_t will escalate until it reaches the steady state. At the beginning of the game, information providers choose the honest strategy and their reputations grows with their choices. However, if due to any reasons an information providers choose dishonest strategy, their reputations will decline and will be penalized immediately as described in Fig. 35. Then the penalized information providers after some time t will note that their fees and taxes amount has increased compared to the originally set fees and taxes. Therefore, next iteration they will try to choose honest strategy and observe the results. During this iteration the information providers will observe reduced fees and taxes compared to the originally set fees and taxes. Therefore, information providers will choose honest strategy to obtain more discounts on fees and taxes. Finally, only honest strategies will be chosen by information providers, and the fraction of honest will achieve a stable state. This conclusion indicates that stakeholders continue to learn from the payoffs gained for each strategy chosen during a game round and adjust their strategies to optimize their payoffs (discount).

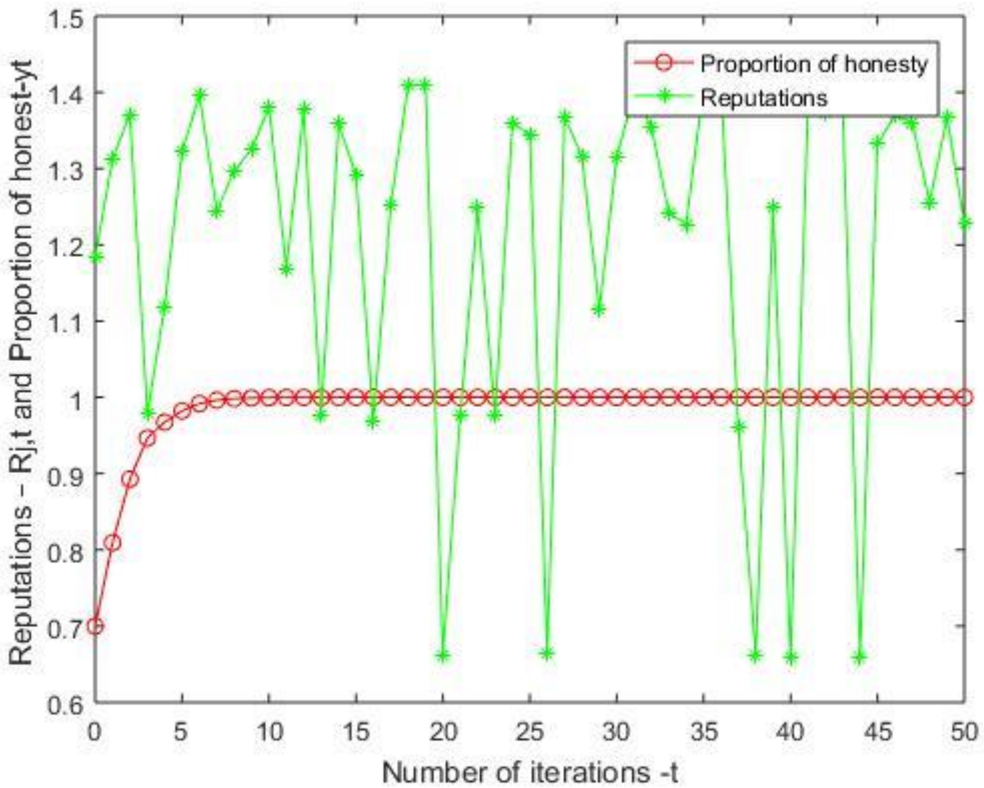


Figure 34: The evolution of y_t and $R_{j,t}$ for initialized value $y_0 = 0.7$

The effect of initialized values of the honest proportion y_0 for information providers is seen in Fig. 36. As seen in Fig. 36, the higher the fraction of honest individuals at the start of the evolutionary process, the quicker the ESS group emerges. The key reason is that if more information providers adopt honest strategy in their population, the remaining dishonest information providers have a high possibility of switching to honest strategy as the game progresses. As a result, there's a good chance that dishonest information providers may switch to a more honest method in order to gain more savings on fees and taxes. As a result, information providers will quickly alter their techniques in order to achieve a more stable condition.

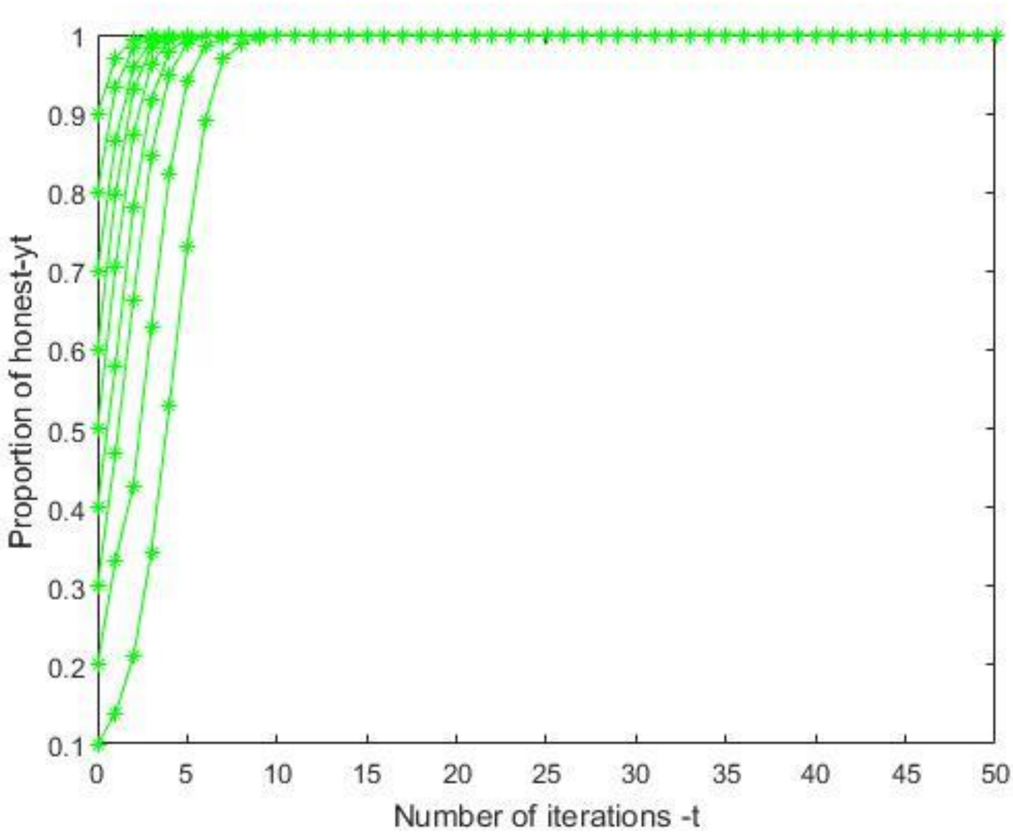


Figure 35: The effect of initialized value y_0 on information users

4.1.3 Proposed Multi-Channel Fisheries Information Gathering and Dissemination Framework

The proposed fisheries information gathering and dissemination architectural framework comprises of four (4) components namely user (user layer), network channels (network layer), application (application layer) and storage (storage layer). The fisheries information gathering and dissemination is a two-way traffic where users can send and receive information via any accessible channel as shown in Fig. 37.

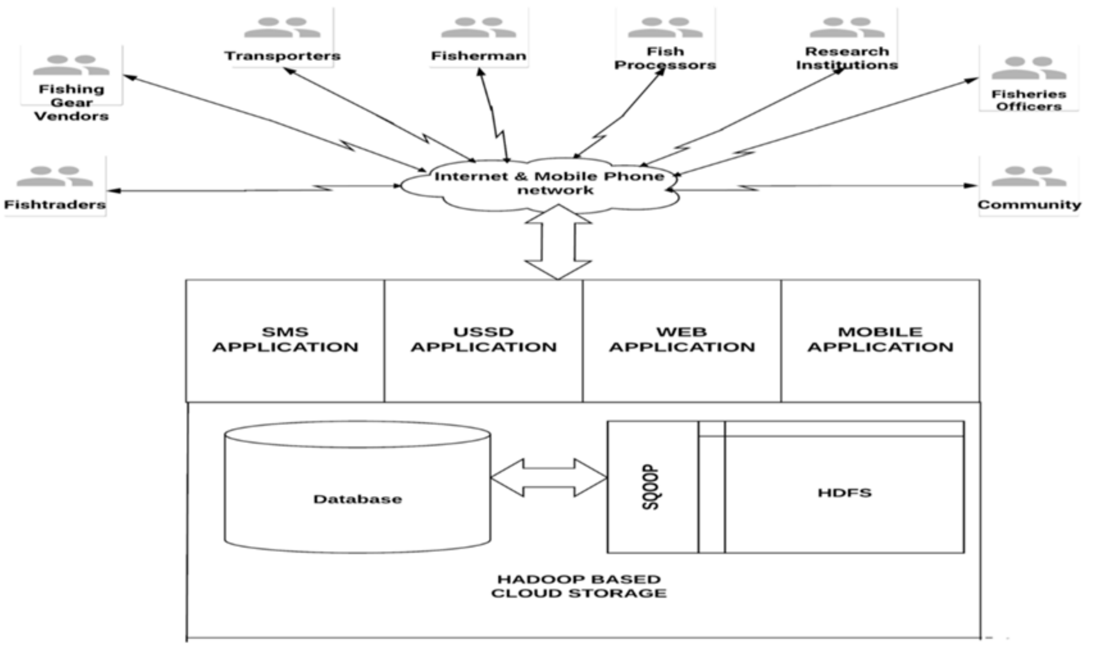


Figure 36: Proposed fisheries information gathering and dissemination framework

(i) Fisheries Information System User

These are fisheries stakeholders (fishers, fish traders, fish processors, fishing gear venders, transporters, fisheries officers, research institutions, community) who uses ICT devices (mobile phone, computer, iPad, PDA's) for accessing needed information to improve their daily activities within and outside the sector. The users can directly receive information (Push) or can request needed information (Pull).

(ii) Network Channels

These are the ICT infrastructure (Mobile phone and Internet network) used to convey the required information from sources of information (provider) to the receivers of information. In this framework sources and receivers of information are the crowd fisheries stakeholders.

(iii) Application

These are the application programs (SMS, USSD, WEB, MOBILE) facilitating the ICT devices to send or receive information. These depends on the capability of the devices as specified by manufacturer.

(iv) Storage

This is a repository that stores all gathered and disseminated information by crowd fisheries stakeholders. It interfaces with crowd fisheries stakeholders, ICT devices, and ICT infrastructures in the process of gathering and dissemination of various information related to fisheries sector.

4.2 Discussion

This study examined the currently ICT tool owned by fisheries stakeholder, its use in accessing and disseminating fisheries information. It was revealed that, different stakeholder has different specific channel access. A reasonable number of fisheries stakeholders have access to radio and television. However, majority of them does not listens fisheries program neither watch television fisheries program due to various reasons (lacking awareness of such program availability, unfavourable air time schedule of the program, lack of customized fisheries programs, etc). Furthermore, study revealed that majority fisheries own mobile phone and uses it to communicate to known fellow stakeholders for searching or sharing fisheries information. Study also revealed that different channels have different information dissemination effectiveness for various fisheries stakeholders. Television and radio have zero effective dissemination probability for both fisheries stakeholders. The reasonable number of stakeholders (88.3%) who do not listen to fisheries programs via radio or watch fisheries programs on television due to various reasons contributed to the zero effective dissemination probability. Some of these reasons include lack of television and radio access, program timing challenge, and non-tailored fisheries program availability. This result is contrary to other studies which revealed that more than 50% of fishers listen to the radio and watch television program about fisheries (Basavakumar *et al.*, 2011; Omar & Chhachhar, 2012; Philip & Udoh, 2011).

The SMS and USSD are most useful to fishers, followed closely by fisheries officers and fish traders. The SMS, and USSD have an essential role in gathering and disseminating fisheries information because they feature higher information dissemination effectiveness for both stakeholders. The higher number of stakeholders owning featured mobile phone about (92.5%) facilitate this effectiveness. Our result agrees with other studies which reveal that fishers use mobile phones to communicate with their friends and related agencies to get information (Omar & Chhachhar, 2012; Salia *et al.*, 2011; Zobidah *et al.*, 2011). These findings attest that Cellular phone call, SMS, and USSD are a useful channel to both stakeholders. However, the cellular phone call is costly compared to SMS and USSD and maybe challenge to fishers.

Furthermore, results show a significant number of stakeholders own smart phones and majority have limited access to computer and portable digital accessory (PDA). Thus mobile application has a significant role in gathering and disseminating fisheries information because they feature higher information dissemination effectiveness for fisheries officers and fish traders. These stakeholder groups can best use the channel because most of them own smart mobile phones capable of running mobile applications. The website is only most effective for fisheries officers and less useful to fish traders. These stakeholder groups (fisheries officers and fish traders) can use the mobile application channel because they have access to internet services.

The comparative analysis of the dynamics evolution simulation results for both information users and information providers confirmed that after several game rounds, the majority of stakeholders will be motivated to choose an honest strategy, regardless of the population of stakeholders or the high number of stakeholders choosing dishonest strategy at the start of the game. As a result, EPRIGM can successfully incentivize stakeholders in crowd fisheries to utilize the system, give correct data, and provide honest comments.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The goal of this research project was to design and hypothesis an evolutionary game-theoretical model for reliable multi-channel information gathering and dissemination. The study looked into the ICT channels that fisheries stakeholders own and utilize to obtain and disseminate information. The purpose of the channel investigation was to determine which route best suited which stakeholder group for gathering and disseminating fishery data. The likelihood of channel effectiveness for six channels was estimated and compared to each stakeholder group. Based on the findings of the complete comparison, it was determined that no single channel can successfully serve all fisheries stakeholders. To address this issue, the researchers developed a multi-channel fisheries information management system architectural framework that would allow all stakeholders to participate effectively in the collection and transmission of fisheries data.

In addition, the study devised and built an evolutionary game theoretical model to aid in the accurate and honest usage of the fisheries information gathering and dissemination system framework. To incentivize honest users and penalize dishonest users, the model used participation and reputation as a criterion. Both information users and information providers had their dynamics simulated empirically. The comparative study of the experimental simulation findings demonstrated that after numerous game rounds, the majority of stakeholders will be motivated to select honest strategy, regardless of the population of stakeholders or the higher number of dishonest stakeholders at the start of the game.

5.2 Recommendations

The developed multi-channel fisheries information management system architectural framework and an evolutionary game theoretical model can facilitate effective involvement, truthful and honest use of fisheries information gathering and dissemination system among fisheries stakeholders. To achieve the deployment of the multi-channel fisheries information management system which employs participation-reputation based incentive scheme, this study appeals to the Government to establish supportive policies to enable private-public partnerships in system development, channel acquisition, and system management. The developed multi-channel fisheries information management system should support all data format supporting the ICT tools owned by fisheries stakeholders.

In this study, we deliberated only seven parameters, namely channel coverage, listening ratio, watching ratio, channel access, average access time, information usefulness, and information sharing, in calculating appropriate probability. The study recommends future work to consider additional factors that affect information dissemination, including channel carrying capacity and channel costs. The EPRIGM can be utilized in different systems to solve human users' dishonest behavior with minor alterations depending on the nature of the system. Furthermore, this research suggests that future work be done to investigate evolutionary games in more complex systems from different industries and to provide appropriate incentive mechanisms.

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APPENDICES

Appendix 1: Fisheries stakeholder's Questionnaire

Fisheries stakeholder questionnaire

Dear research respondent;

I sadiki Lameck kusyama;a PhD candidate in Information Communication Science and Engineering (ICSE) at Nelson Mandela Institution of Science and Technology, Kindly inviting you to participate in this research by providing fisheries related information as directed by this questionnaire.

The goal of this research work is to enhance accessibility of information in fisheries sector by developing a novel fisheries information gathering and dissemination system framework which will enable all stakeholders to share and exchange information. The developed framework will provide proper guidance in developing and implementing fisheries information management systems in near future.

I assure you that all information provided will be used strictly for research purpose and treated confidential. Thank you very much for you are valuable cooperation.

Yours,

Sadiki Lameck Kusyama

PhD candidate.

Part A: Personal information (place (√) in the appropriate answer)

1. What is your gender?
   - ☐ Me
   - ☐ Fe
2. What is your age range?
   - ☐ Below 18 years old
   - ☐ Between 19-45 years old
   - ☐ Between 46-60 years old
   - ☐ above 60 years old
3. What is your highest education level?
   - ☐ Primary education
   - ☐ Secondary education

□ Certificate professional education

□ Diploma education

□ Degree and above education

4. For how long have you working in fisheries sector?

□ Below 5 years

□ Between 5-10 years

□ Between 11-20 years

□ Between 21-30 years

□ Between 31-40 years

□ Over 40 years

5. What kind of species of fish do you normally catch or trade?

□ Sardine (Dagaa)

□ Nileperch

□ Tilapia

□ Not applicable

6. What kind of role you're playing in the fisheries sector?

□ Fisher (Fisherman)

□ Fisheries officer

□ Fishtrader

Part B: Collection and dissemination of fisheries information (place (√) in the appropriate answer)

7. Have you been involved in providing or gathering fisheries information before?

□ Yes

□ No

8. Which mode (s) did you use to provide, gather or disseminate fisheries information?

□ Seminar

□ Landline telephone

□ Mobile phone

□ Internet

□ Questionnaire

□ Interview

□ CD and DVD

□ TV and Radio

□ Not applicable

9. Do you have access to fisheries information?
   □ Yes
   □ No
10. Do you have access to radio receiver?
   □ Yes
   □ No
11. Do you listen fisheries programs from radio?
   □ Yes
   □ No
12. Do you have access to television (TV)?
   □ Yes
   □ No
13. Do you watch fisheries program on television (TV)?
   □ Yes
   □ No
14. Do you have access to computer?
   □ Yes
   □ No
15. Do you access fisheries information through computer?
   □ Yes
   □ No
16. Do you have access to Portable Digital Accessory (PDA)?
   □ Yes
   □ No
17. Do you access fisheries information through Portable Digital Accessory (PDA)?
   □ Yes
   □ No
18. Do you own mobile phone?
   □ Yes
   □ No
19. Which type of mobile phone do you own?
   □ Featured mobile phone
   □ Smart mobile phone

20. Do you access fisheries information through mobile phone?

 Yes

 No

21. Do you share your fisheries experience in fisheries with your fellow stakeholders?

 Yes

 No

22. Which mode do you use to share your fisheries experience with your fellow stakeholders?

 Physical visit

 Mobile phone

 WhatsApp

 Internet

23. What kind of fisheries information would you prefer to acquire for improving your occupation?

 Best fishing practice

 Fishing gears

 Market price

 Financial credits

 Policy and guidelines

 Weather forecast

 Security measures

 Transportation

24. In what format would you prefer to receive fisheries information?

 Text

 Image

 Video

 Audio

25. How often would you prefer to access fisheries information?

 Daily

 Weekly

 Monthly

 annually

 On demand (Request)

Appendix 2: EPRIGM simulation codes

```
% =========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi  Laboratory     =
          % GameAnalysis.m
% =========================
clear; %clear work space
clc;    % clear command window
run('.\\Gparameters.m');  % load the simulation parameters
run('.\\GameAnalysis2.m');
info2_proportion(x0,a,b,c,I,P,delta,tf)
info_proportion(x0,a,b,c,I,P,delta,tf) % plots xt and Ri,t on the same axis.
% plots xt at different x0
[x,t]=honest_proportion4dx(0.1,a,b,c,I,P,delta,tf);
figure;
%plot(t,x,'-*g') %
plot(t,x,'-g')
ylabel('Proportion of honest-yt ')
xlabel('Number of iterations -t')
hold on
for i = 0.2:0.1:0.9
[x,t]=honest_proportion4dx(i,a,b,c,I,P,delta,tf);
%Create graph with random color
plot(t,x,'Color',[rand,rand,rand])
hold on
end
hold off
```

```
% ========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi  Laboratory     =
%  GameAnalysis2.m
% ========================
clear; %clear work space
clc;    % clear command window
run('.\\Gparameters.m');  % load the simulation parameters
[x,t]=honest_proportion4dx(0.1,a,b,c,I,P,delta,tf);
figure;
%plot(t,x,'-*g') %
plot(t,x,'-r')
ylabel('Proportion of honest-xt ')
xlabel('Number of iterations -t')
hold on
for i = 0.2:0.1:0.9
[x,t]=honest_proportion4dx(i,a,b,c,I,P,delta,tf);
%Create graph with random color
plot(t,x,'Color',[rand,rand,rand])
hold on
end
hold off
```

```
% ==========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi  Laboratory     =
        % Gparameters.m
% ==========================
x0 =0.7
delta = 1;
tf = 50;
a = round(rand(1),3)
b = round(rand(1),1)
c = round(rand(1),1)
I = round(rand(1),1)
P = round(rand(1),1)
F = randi(10)

% ==========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi  Laboratory     =
% ==========================
% This function plots the evolution of xt and Ri,t
% for initialized state x0
% =0.7
% ==================================================
function [ x, t ] = honest_proportion4dx(x0, a,b,c,I,P,delta, tf )
t = 0:delta:tf; % create time array
x(1) = x0; % initilize

for i = 1:length(t)
```

```
    m = randi(20);
%     fprintf(' Generated  m = %d\n',m);
    n = randi(20);
%     fprintf(' Generated n = %d\n',n);
    q = atan(m)/pi;
    r = atan(n)/pi;
    R(i) = a*q*exp(b*exp(c*r*q));
    if i<length(t)
       x(i+1) = x(i) + delta * (x(i) - (x(i)).^2)*(R(i)*I + q*P);
    end
end
end

% ==========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi Laboratory      =
% ==========================
% This function plots the evolution of xt and Ri,t
% for initialized state x0
% =0.7
% ==================================================
function [ x, t ] = honest_proportion4dx(x0, a,b,c,I,P,delta, tf )
t = 0:delta:tf; % create time array
x(1) = x0; % initilize
for i = 1:length(t)
    m = randi(20);
%     fprintf(' Generated  m = %d\n',m);
    n = randi(20);
%     fprintf(' Generated n = %d\n',n);
    q = atan(m)/pi;
```

```
    r = atan(n)/pi;
    R(i) = a*q*exp(b*exp(c*r*q));
    if i<length(t)
       x(i+1) = x(i) + delta * (x(i) - (x(i)).^2)*(R(i)*I + q*P);
    end
end
end

% =========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi Laboratory      =
% =========================
% This function plots the evolution of xt and Ri,t
% for initialized state x0
% =0.7
% ==============================================
function [ x, t ] = info_proportion( x0,a,b,c,I,P,delta, tf )
t = 0:delta:tf; % create time array
x(1) = x0; % initilize
for i = 1:length(t)
    m = randi(20);
%     fprintf(' Generated  m = %d\n',m);
    n = randi(20);
%     fprintf(' Generated n = %d\n',n);
    q = atan(m)/pi;
    r = atan(n)/pi;
    R(i) = a*q*exp(b*exp(c*r*q));
    if i<length(t)
       x(i+1) = x(i) + delta * (x(i) - (x(i)).^2)*(R(i)*I + q*P);
    end
```

```
end
figure;
plot(t,x,'-or')
ylabel('Reputations – Rj,t and Proportion of honest-yt ')
xlabel('Number of iterations -t')
hold on
plot (t,R,'-*g')
legend('Proportion of honesty','Reputations')
hold off
end


% ==========================
% Author: Sadiki Lameck Kusyama =
% Date : 20/10/2021        =
% Place: RaspberryPi Laboratory       =
% ==========================
% This function plots the evolution of xt and Ri,t
% for initialized state x0
% =0.7
% ==================================================
function [ x, t ] = info_proportion( x0,a,b,c,I,P,delta, tf )
t = 0:delta:tf; % create time array
x(1) = x0; % initilize
for i = 1:length(t)

   m = randi(20);
%     fprintf(' Generated  m = %d\n',m);
   n = randi(20);
%     fprintf(' Generated n = %d\n',n);
   q = atan(m)/pi;
```

```
    r = atan(n)/pi;
    R(i) = a*q*exp(b*exp(c*r*q));
    if i<length(t)
        x(i+1) = x(i) + delta * (x(i) - (x(i)).^2)*(R(i)*I + q*P);
    end
end
figure;
plot(t,x,'-or')
ylabel('Reputations – Ri,t and Proportion of honest-xt ')
xlabel('Number of iterations -t')
hold on
plot (t,R,'-*b')
legend('Proportion of honesty','Reputations')
hold off
end
```

RESEARCH OUTPUTS

(i) Published papers

Kusyama, S. L., Machuve, D., Kisangiri, M., & Mfanga, A. (2022). Analysis of effectiveness of channels for information gathering and dissemination: Case of fisheries stakeholders in Mwanza and Mara regions of Tanzania. *African Journal of Science, Technology, Innovation and Development,* 14(1), 173-178.

Kusyama, S. L., Machuve, D., Kisangiri, M., & Mfanga, A. (2020). Participation-reputation based incentive game model (PRIGM) for trustworthy fisheries information collection and dissemination framework. *International Journal of Advanced Technology and Engineering Exploration*, 7(70), 137.

(ii) Poster Presentation