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RESEARCH ARTICLE

Economic Benefits and Uses of Indigenous Seasonal Weather Forecasts in Zimbabwe

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ABSTRACT

This study presents a seminal contribution regarding the economic value of indigenous seasonal weather forecasts in Zimbabwe. Many farmers (58%) use indigenous seasonal weather forecasts to make maize farming decisions such as selecting suitable varieties. The main indicators used for indigenous seasonal weather forecasts are flowering and fruition of specific trees. Based on travel cost analysis, which incorporates a multi-purpose visit scenario, the study establishes the economic importance of indigenous seasonal weather forecasts with a consumer surplus of US$1,044 per year among the 290 farmers using the forecasts. There is therefore a need to integrate indigenous weather forecasts into national seasonal weather forecasting and disaster risk reduction systems to complement modern seasonal weather forecasts. Co-production of seasonal weather forecasts with farmers is proposed in this regard. This further calls for the need to digitally document, visualize, and disseminate indigenous seasonal weather forecast indicators to a wider audience to increase their use.

Keywords: Indigenous seasonal weather; Maize farmers; Travel cost; Co-production; Zimbabwe

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1. Introduction

Farmers in Zimbabwe are increasingly facing climate change-related risks such as drought and long mid-season dry spells [1–6]. Therefore, it is now more important than ever to have timely, accurate, location-specific, affordable, and accessible seasonal weather forecasts to minimize the loss and damage associated with climate change. Access to seasonal weather forecasts allows farmers to make informed farming decisions to mitigate the impacts of rainfall variability and take advantage of favorable weather conditions [7–9]. Despite significant efforts being made to strengthen access to modern seasonal weather forecast services in Zimbabwe, access to these services remains a challenge among smallholder farmers who are most vulnerable to the effects of climate change [9–13]. Apart from access challenges, just like in other African countries like Malawi, some farmers do not use modern seasonal weather forecasts due to a lack of trust; limited applicability and understandability; and inaccurate [10, 12, 14–16]. As a result, most farmers rely on indigenous seasonal weather forecasts to predict the seasonal weather outlook [10, 14, 17, 18]. This means that combining modern and indigenous seasonal weather forecasts is necessary [8, 10, 15, 16, 19].

Such hybrid seasonal forecasts are more likely to strengthen the trust and use of seasonal weather forecasts across the country in farming decisions [8, 14, 20–24]. Traditionally, just like in other African countries like Benin, Ethiopia, Kenya, and Malawi, farmers in Zimbabwe have used indigenous seasonal weather forecasts to inform farming decisions such as scheduling planting dates [7, 15, 16, 18, 22, 25]. Recent evidence showed that the use of indigenous seasonal weather forecasts tripled the uptake of climate change adaptation strategies among smallholder farmers in drought-prone areas of the Chiredzi district of Zimbabwe [18]. About 82% of farmers in other drought-prone districts of Zimbabwe (Mbire, Matobo, Binga, and Mudzi) also indicated that they used both indigenous and modern seasonal weather forecasts to inform farming decisions [14]. Thus, the need to integrate indigenous and modern seasonal weather forecasts cannot be overstated.

However, to better inform the Zimbabwe Meteorological Service Department (ZMSD), the country's meteorological service agency, about the necessity of integrating both indigenous and modern seasonal weather forecasts, a deeper comprehension of the economic benefits of indigenous seasonal weather forecasts among farmers is required. This will help the ZMSD modify seasonal weather forecast products and delivery methods to address the needs and preferences of farmers [7, 26]. Though many Zimbabwean farmers rely on traditional seasonal weather forecasts, little is known about the forecasts' potential economic benefits. To the best of our knowledge, this study is the first attempt to estimate the economic value of indigenous seasonal weather forecasts in Southern Africa and Zimbabwe in particular. Prior studies mainly focused on documenting the indicators used to predict seasonal weather outlooks based on Indigenous knowledge and how farmers use the indigenous seasonal weather forecasts in their farming decisions [10, 14, 16, 18, 21]. As such, this study departs from previous studies by estimating the economic value of indigenous seasonal weather forecasts through the travel cost analysis. The travel cost analysis takes into account all the costs associated with or incurred by farmers in searching for indigenous seasonal weather forecasts. This approach is applicable in the Zimbabwean context since farmers travel to the sources of seasonal weather forecasts such as elders and religious leaders [16]. The research objectives addressed in this study are to (a) examine the economic benefits of indigenous seasonal weather forecast services in Zimbabwe; and (b) identify uses of indigenous seasonal weather forecasts that are of interest to maize farmers in Zimbabwe.

In this study, indigenous seasonal weather forecasts are seasonal forecasts based on local knowledge accumulated by people over a long period from their experiences, observations, practices, and interactions with nature [18, 20, 27, 28]. This forecasting system is passed from one generation to the other and can complement scientific data with precise information based on well-established indicators such as observing the behavior of birds or flowering or fruition of certain trees [7, 17, 18, 20, 27].

The contribution of this study is twofold. First unpacking the benefits of indigenous weather forecast services could help to unlock opportunities for co-production and embedding indigenous knowledge in seasonal weather and climate services production and dissemination. Second, to the best of our knowledge, this study presents a seminal contribution to knowledge concerning the economic value of traditional seasonal weather forecasts in Zimbabwe. Thus, the study presents a useful case to place indigenous seasonal weather forecasts at the center of the climate change adaptation agenda and to integrate them into national weather forecasting systems.

This paper is organized into four key sections. Apart from this introduction part, the second section presents the methods employed in this study to collect and analyze the data to address the research questions. The third section describes and discusses the main results of the study while the conclusions and recommendations are provided in the final section.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Manicaland province in Zimbabwe, particularly in Mutare Rural, Chipinge, Chimanimani, Makoni, and Buhera districts. The province is generally inhabited by people who follow the patriarchal inheritance system. The major ethnic group is the Shona with Manyika, a subgroup being the most dominant in the area. Although English is the official language for business, mainly in urban areas, Shona is the major local language with local dialects like Manyika and Ndau being the most common in the province. The name of the province is derived from the biggest tribe, the Manyika. The major economic activity in the province is agriculture; maize is the chief staple crop among smallholder farmers. Mining and tourism are also important economic industries in the province with Nyanga, Chimanimani, and Vumba Mountains as well as Mutarazi and Nyagombe Falls being key tourism attraction destinations [29, 30].

2.2. Data and Data Collection Methods

The target population for this study was smallholder farmers in Mutare Rural, Chipinge, Chimanimani, Makoni, and Buhera districts engaged in maize production. From the list of farmers provided in each district, a total of 502 farmers were randomly selected and interviewed for the study. Data were collected through a household questionnaire as the main instrument. The questionnaire was deployed through the KoBo Collect software and a total of eight enumerators were trained to assist in administering the survey questionnaire. Verbal consent to participate in the study was requested before each household head or designated household head was interviewed confidentially. The interviews of household heads were conducted at the times of choice of the heads and their suggested places of convenience for the interviews. Before the commencement of data collection, the study also received ethical approval from the Ethics Committee for Basic and Applied Sciences (ECBAS) at the University of Ghana, Legon, Accra (ECBAS 002/23-24). Permission to conduct the data collection was also granted by all the responsible authorities including the senior management of the Ministry of Lands, Agriculture, Fisheries, Water and Rural Development in Manicaland Province, district development coordinators, and village heads.

The questionnaire consisted of five key sections. The first section provided an opportunity for farmers to value indigenous weather forecast services by capturing all the expenses involved in the farmer acquiring the forecast information in the community. These expenses incurred by farmers in visiting the sources of indigenous seasonal weather forecasts were used to estimate the economic value of indigenous weather forecast services using travel cost analysis. Thus, all the expenditures incurred by farmers to get indigenous weather forecast services were captured. These included the number of trips made by farmers to get the indigenous weather forecast services. Farmers indicated traveling from their homesteads to visit Indigenous weather forecasters or elders who observed the behavior and phenology of natural indicators such as birds, insects, plants, and extra-terrestrial objects to predict the seasonal weather outlook. The cost incurred also included on-site payment to acquire the forecast either in cash or in-kind (this was then converted to a monetary value).

The second and third sections of the questionnaire consisted the questions aimed at the economic valuation of modern seasonal weather forecasts through contingent valuation and choice experiments. The results of these sections of the questionnaire are not reported in this paper. The fourth section elicits information on general crop and livestock production activities. The last section of the questionnaire was devoted to sensitive personal information related to the demographic and socio-economic characteristics of the farmers including sex, income, and religious preferences.

2.3. Theoretical and Analytical Framework

2.3.1. Theoretical Framework

The travel cost method is based on the general expenses model where the economic value of non-market goods, such as recreational sites, is estimated from the actual costs incurred by an economic agent from his/her homestead to a site of interest [31]. This approach is also known as the travel expense method and was initially proposed by Hotelling in 1949 and later used in the first empirical research work in 1959 by Clawson [32]. It is based on the revealed preference method since the estimation of the economic value of the site of interest is based on the observed amount of money and other resources that economic agents incur to reach and utilize the site of interest [31].

Although the travel cost method has been extensively applied in estimating the economic value of recreational sites, such as national wildlife parks, the approach has also been applied to estimate the economic value of weather forecast services (for example, refer to examples by [33] for its use in Australia and [7] for its use in Benin, West Africa). Anaman and Lellyett [33] established a minimum value of the public weather services in Australia for the 1994/1995 financial year based on the costs incurred by the public through phone calls to three types of weather information programs maintained by the Australian Bureau of Meteorology. The estimated value of 2.868 million Australian dollars was equivalent to about 28% of the direct cost of the provision of public weather services including severe weather warning services by the Bureau. Amegnaglo [7] estimated the economic value of indigenous weather forecast services using the travel, search, and related costs incurred by economic agents such as farmers to get weather forecast services.

At the farm level, weather forecast services improve farmers' decision making which translates to increased profits. In this study, the travel cost method is employed to estimate the economic value of indigenous weather forecast services since farmers incur some costs in search of indigenous weather forecast services. Such costs include travel fees and payments made on-site (cash or in-kind) to get the seasonal weather outlook by consulting religious leaders, elders, or indigenous weather forecasters.

Assuming that a farmer is a quasi-rational human being who aims to maximize his or her utility by combining indigenous weather forecast services and other purchased inputs, let U (v, x) be the utility function of an individual farmer. Following [7], v is the number of trips by a farmer to the site of indigenous weather forecast services and x is a vector of all other goods consumed by the farmer at a given price, p. For each trip to the indigenous weather forecast services site, a farmer incurs costs, c. Further assuming that a farmer has income, Y which can be expressed as:

$$Y = Y_0 + w \times t_w \quad (1)$$

Where Y_0 is a non-wage income, w is the hourly wage rate and t_w is the work hours. A farmer has a certain amount of time, T_0 expressed as:

$$T_0 = t_w + v \times t_v \quad (2)$$

Where t_v is the time, a farmer spends per trip to the indigenous weather forecast site. Based on these assumptions, a quasi-rational farmer must maximize his or her utility U(v, x) subject to income and time constraints where:

$$Y = Y_0 + w \times t_w = c \times v + p \times x \quad (3)$$

Substituting related terms this expression yields:

$$Y_0 + w(T_0 - v \times t_v) = c \times v + p \times x \quad (4)$$

$$Y_0 + w \times T_0 - v(w \times t_v + c) - p \times x = 0 \quad (5)$$

Hence the utility-maximizing problem can be rewritten as:

$$\max_{v,x} \{U(v, x) + \lambda(Y_0 + w \times T_0 - v(w \times t_v + c) - p \times x)\} \quad (6)$$

Taking first order differential this yields:

$$\frac{dy}{dx} - (w \times t_v + c) = 0 \quad (7)$$

Then, respectively the total cost of trips and the farmer's maximum income will be given by:

$$\begin{aligned} C* &= w \times t_v + c \\ Y* &= Y_0 + w \times T_0 \end{aligned} \quad (8)$$

As a result, the demand for indigenous weather forecast services can be expressed as a function of farmers' income, the cost of trips to indigenous weather forecast information sources, and the price of other goods and services consumed. This can be expressed as:

$$V = f(Y^*, p, c^*) \quad (9)$$

Like visiting a recreational site, the higher the cost per trip, the lower the number of trips; the higher prices of other goods consumed reduce farmers' ability to spend more money on the acquisition of indigenous weather forecast services. On the other hand, a higher income enables an individual to spend a larger proportion of income to get indigenous weather forecast services. These are the basic relationships that motivate the travel cost analysis used in this study. This relationship is essentially driven by the Marshallian demand function concept originally proposed by Alfred Marshall in 1890 [34].

2.3.2. Analytical Framework

The travel cost analysis based on the total expenditures incurred approach was employed to estimate the economic value of indigenous weather forecasts. This method involved the summation of all the costs incurred in accessing the indigenous seasonal weather forecasts from either indigenous weather forecasters elders or religious leaders. All the costs including the return transport costs, proxy time costs, and onsite payment expenditures to the indigenous weather forecaster were then multiplied by the number of trips per farmer (Equation 10).

$$\begin{gathered} \text{Totalexpendituresincurred} = [\text{searchcosts} \\ (\text{phonecalls}) + \text{returntriptransportcosts} + \\ \text{onsitepayments} + \text{proxytimecosts}] * \\ \text{numberoftrips} \end{gathered} \quad (10)$$

The proxy time costs, or the opportunity cost of time a farmer sacrifices to get indigenous seasonal weather forecasts, were determined by multiplying the time (days) spent visiting the source of the forecasts by the average daily wage rate in Zimbabwe's agricultural sector. The average daily wage of US$3.18 was used (22 working days a month) based on the minimum monthly wage of US$70 for the general agricultural sector as of March 2024 according to the National Employment Council for the Agricultural Industry in Zimbabwe. This approach of estimating the opportunity cost of time was also employed in literature [7].

The total expenditures incurred by farmers to get indigenous weather forecast services were used as the estimate of the economic value of indigenous seasonal weather forecast services. Nevertheless, to avoid overestimation of the consumer surplus, the trip to visit the source of indigenous seasonal weather forecasts was analyzed as a multi-purpose visit. This is because farmers also engage in other purposes apart from inquiring about the indigenous seasonal weather forecasts. In this study, three other purposes were observed which are social visits, religious festivals, and traditional ceremonies. Thus, asking for indigenous weather forecasts was treated as one of the four main purposes of the trip. As such, the total costs incurred per trip were divided by four to reflect the costs associated with searching for indigenous seasonal weather forecasts.

Given that some of the farmers reported visiting frequency of once in two years to the source of Indigenous weather seasonal weather forecasts, to determine the factors affecting visiting frequency, a semi-log regression model was employed. Such a log-normal model has several advantages over the Poisson and negative binomial regression models. Firstly, the semi-log model accommodates farmers who report less than one visit per year, such as once every two years (0.5 per year), as was the case with around 19% of farmers in this study. Secondly, the model also applies to farmers who make several trips within a year to the source of indigenous seasonal weather forecasts. In this study, 28% of farmers reported visiting the elders or indigenous weather predictors three (1.5 trips a year) or five times in two years (2.3 trips a year). The semi-log model also accepts count data from farmers who report one or two visits per year just like the Poisson and negative binomial models. The semi-log model is also conveniently applicable in calculating the consumer surplus as a result of visiting the source of indigenous seasonal weather forecasts. Given these desirable properties over Poisson and negative binomial models, the semi-log model was employed to determine the factors affecting visiting frequency to the source of the forecasts as suggested by various research scholars [35–39].

The travel cost model is mostly estimated as a latent demand, Y_i, representing the number of trips per year to the source of indigenous seasonal weather forecasts by a farmer (in log form) as a function of travel costs (C_i), and farmer's socio-economic characteristics (X_i).

$$LnY_i = \alpha C_i + X_i\beta + \varepsilon \quad (11)$$

Where a is the cost coefficient, β is a vector of coefficients to be estimated for the socio-economic characteristics of farmers (as guided by the conceptual framework of this study; these include the sex of household head, farming experience, location, religious preferences, and access to extension services), and e is the equation error term.

Apart from understanding the factors affecting the frequency of visits, the consumer surplus per trip to the source of indigenous seasonal weather forecast service was also calculated. This was expressed as the inverse of the travel cost coefficient [36–38]:

$$Consumersurpluspertrip = -1/a \quad (12)$$

The total consumer surplus accrued by all the farmers from using Indigenous seasonal weather forecast services per year was then calculated by multiplying consumer surplus per trip ($-1/a$) by the average trips reported by all farmers using Indigenous seasonal weather forecasts.

To address the potential for heteroscedasticity, a robust semi-log model was estimated that computes robust standard errors [40]. To check the presence of multicollinearity, the variance inflation factors (VIF) and Tolerance (the inverse of VIF) were used. A VIF below 10 and a Tolerance value closer to one means a lack of multicollinearity problem [41]. The overall model fit was tested by the F-test. A statistically significant F-test means that the model fits the data well [42].

3. Results and Discussion

3.1. Socio-Economic Characteristics of Farmers

Most of the interviewed farmers came from female-headed households (63%). The average age of the farmers was 52 years old. A slight majority (51%) of the respondents had received secondary school education with an average of nine (9) years of education and 75 United States Dollars (US$) monthly income. The average household size was six and most of the farmers (86%) were Christians while 14% were adherents of African Traditional Religions. All the 502 respondents belonged to the Shona broad ethnic group; 77% of them belonged to the Manyika subgroup or tribe while the remaining 23% were from the Ndau tribe (refer to **Table 1** for more detailed information).

Disaggregating farmers' key socio-economic characteristics based on the use of Indigenous seasonal weather forecasts indicated that most small-scale commercial farmers do not use indigenous seasonal weather forecasts compared to farmers engaging in subsistence farming. Further, farmers who use indigenous seasonal weather forecasts reside in distant areas, an average of 49 kilometers from the district capital (nearest town). This distance is 18 kilometers further than the average distance from the district capital, where farmers not using indigenous seasonal weather forecasts reside. This suggests that farmers using indigenous seasonal weather forecasts generally reside in remote rural areas.

Farmers who use indigenous seasonal weather forecasts are also older, have more maize farming experience, are more educated, and belong to the Ndau tribal group, with higher income and larger land holdings than farmers who do not use indigenous seasonal weather forecasts (**Table 1**).

Table 1. Disaggregating farmers' characteristics based on the use of Indigenous forecasts.

Variable	All Farmers	Use of Indigenous Seasonal Weather Forecasts		
		Yes	No	Difference
Perceiving climate change (1-yes, 0 otherwise)	96%	97%	95%	2%
Small-scale commercial farming (1-yes, 0 otherwise)	14%	10%	19%	−9%***
Access to extension services (1-yes, 0 otherwise)	82%	81%	84%	−3%
Member of a farming group (1-yes, 0 otherwise)	27%	30%	23%	7%*
Distance to the nearest town in kilometers (continuous)	39	49	31	18***
Sex of household head (1 male, 0 female)	37%	38%	36%	2%
Subscribe to African Traditional Religions (1-yes, 0 otherwise)	14%	16%	13%	3%
Years of education (continuous)	9	9	8	1***
Years of maize farming experience (continuous)	21	24	19	5***
Farmer's age (continuous)	52	54	50	4***
Belong to the Ndau ethnic group (1-yes, 0 Manyika)	23%	29%	16%	13%***
Low rainfall regions (1-yes, 0 otherwise)				
Monthly household income in US$ (continuous)	75	81	67	14**
Total land size in hectares (continuous)	2.2	2.3	1.9	0.4***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source: Survey data, 2024.

3.2. Awareness and Indicators of Indigenous Seasonal Weather Forecasts

The majority of the farmers were aware of indigenous weather forecasts (70%). Similar findings of high awareness of indigenous seasonal weather forecasts were also noted in other districts in Zimbabwe [14, 18]. All the farmers who were aware accessed the forecasts by traveling to the source of indigenous weather forecasts. The main sources of indigenous seasonal weather forecasts were elders in the village (70%) followed by fellow farmers (14%) (**Table 2**). In many villages in Africa, elders are seen as beacons of indigenous knowledge about weather patterns, which is required for climate change adaptation. In Benin, West Africa, elders are the main source of indigenous weather forecasts [7]. Likewise, in Ghana, Ethiopia, Kenya, Tanzania, and Uganda, elders are the most trustworthy sources of weather forecasts since they are regarded to have experience observing indigenous weather forecast indicators [22, 43, 44]. Generally, the indigenous seasonal weather forecasts are based on cumulative experience and repeated observations [17].

The main indigenous seasonal weather forecast indicators were observing the flowering of specific trees (51%), the behavior of certain birds (33%), and high temperatures at night (21%) (**Table 3**). These indicators were used to forecast the seasonal weather outlook before the onset of the rainy season. Under the tree-based indicators, the flowering and fruiting of specific trees were the most used indicators across all the districts. Early flowering of the Mopane tree indicates the early onset of the rainy season [18]. The flowering of trees is regarded as the most frequently used indigenous season weather forecast indicator in Zimbabwe [21]. Farmers using animal-based indicators such as the behavior of certain birds were also noted. Large flocks and singing of most birds in October and November indicate that the rainy season would be characterized by high rainfall amounts. For example, the appearance of large flocks of swallows and weaver birds in October means the onset of the rainy season. With regards, to the astrological and atmospheric indicators, temperatures at night, the strength and direction of winds, and the appearances of clouds and moon are mostly utilized to predict the seasonal weather outlook. High temperatures at night in September and October indicate that the rainy season is about to start and will be characterized by heavy amounts of rain with thunderstorms. The appearance of dark clouds for several consecutive days in October was observed to indicate the onset of the rainy season. Occurrences of strong winds for several days in October and November would indicate that the rainy season would be characterized by low levels of rainfall. Across all the districts, the direction of winds, from east to west, could indicate that the rainy season would be characterized by low rainfall.

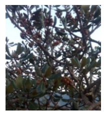
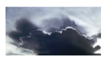
These indicators are not unique to Manicaland Province but are also used in many contexts to predict the weather outlook of the farming season [18, 23, 24, 45].

Table 2. Awareness and source of Indigenous seasonal weather forecasts.

Variables Definition Awareness of Indigenous Weather Forecasts	Variable Description	Percentage
Awareness		
Aware of Indigenous weather forecasts	1 if the farmer is aware of indigenous weather forecasts and 0, otherwise	70%
Source of Indigenous seasonal weather forecasts		
Elders in the village	1 if the source is an elder and 0, otherwise	70%
Fellow farmers	1 if the source is a fellow farmer and 0, otherwise	14%
Traditional leaders	1 if the source is a traditional leader and 0, otherwise	6%
Religious leaders	1 if the source is a religious leader and 0, otherwise	6%
Traditional forecaster	1 if the source is a traditional forecaster and 0, otherwise	4%

Source: Survey data, 2024.

Table 3. Indigenous seasonal weather forecast indicators.

Indicator Indicators	Indicator Description			Percentage of Respondents
Flowering and fruits of specific trees and sprouting of young shoots	Wild Loquat tree		High fruitage means low rainfall is anticipated for the upcoming season and is usually a drought	51%
Behavior of certain birds	Swallows		Large flocks of swallows or birds singing indicate the onset of the rainy season	33%
High temperatures at night	High temperatures at night indicate that the rain season will be characterized by heavy rains with thunderstorms			21%
Direction and strength of wind	Occurrence of strong winds for several days in October and November indicate that the rain season will be characterized by low rainfall			18%
Appearance of clouds	Dark clouds		Dark clouds indicate that the rainy season is about to start	15%
Appearance of moon	Halo around the moon		The onset of the rainy season is characterized by heavy rains	6%
Large numbers of ants	An army of ants		The onset of the rainy season is characterized by heavy rains	3%

Source: Survey data, 2024.

For instance, in Kenya, farmers observe the behavior of certain trees, birds, the moon, and the direction of wind as the key indicators of indigenous seasonal weather forecasts [22, 44]. Farmers were asked to rate the attributes of indigenous seasonal weather forecasts and many of them agreed that the forecasts were accurate (44%), reliable (38%), and easy to interpret (38%) (**Table 4**). This observation was like other studies which showed that many farmers in remote rural areas in Africa use indigenous seasonal forecasts as they are easily accessible, reliable, and easy to interpret [7, 10, 14, 25, 46].

3.3. Uses of Indigenous Seasonal Weather Forecasts in Maize Production

With regards to the use of indigenous seasonal weather forecasts, 290 farmers (58%) used indigenous seasonal weather forecasts to inform maize farming decisions during the 2022/23 farming season (**Table 5**). Disaggregating use by district, 74% of farmers in Buhera used indigenous weather forecasts followed by Mutare Rural (72%), Chimanimani (68%), Makoni (53%), and then Chipinge (33%).

Most of the farmers used Indigenous seasonal weather forecasts to inform the choice of suitable maize varieties (58%), scheduling planting dates (36%), and

Table 4. Farmers' rating of Indigenous seasonal weather forecasts attributes.

Variable	Not Considered An Attribute at All	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Accurate	2%	10%	13%	31%	29%	15%
Easy to interpret	3%	12%	20%	27%	24%	14%
Reliable	3%	11%	18%	30%	25%	13%
Easily observable	7%	13%	20%	25%	24%	12%

Source: Survey data, 2024.

land preparation (21%) (**Table 5**). These findings concur with other previous studies which showed that many farmers in African countries rely on indigenous weather forecasts to inform farming operations [7, 17, 21, 24, 43]. For example, in Benin, during the 2014 farming season, most maize farmers used Indigenous seasonal forecasts to schedule land preparation, planting, fertilizer, and chemical application [7]. Similar results were also noted in the Chiredzi district of Zimbabwe where most smallholder farmers rely on indigenous weather forecasts to schedule land preparation, select suitable crop varieties, and timing of planting dates [18]. Likewise, in Kenya, most smallholder farmers also use Indigenous weather forecasts to schedule land preparation and planting dates as well as select suitable crops to grow [22]. Thus, the current study further underscores the importance of indigenous seasonal weather forecasts in informing farming decisions and adaptation to climate change. Mainstreaming the indigenous seasonal weather forecasts in climate change adaptation and resilience-building initiatives is paramount to boosting agricultural productivity.

3.4. Economic Benefits of Indigenous Seasonal Weather Forecasts in Maize Production

3.4.1. Value of Indigenous Seasonal Weather Forecasts Based on Total Expenditure Approach

As farmers get Indigenous seasonal weather forecasts by visiting the sources of the forecast information, there are costs involved in traveling to and from the source. These costs were used to reflect the economic value of indigenous seasonal weather forecasts. On average a farmer traveled two kilometers to get the indigenous seasonal weather forecasts either from elders in the village or fellow farmers or traditional leaders, religious leaders, or traditional forecasters. Farmers also visit the source of indigenous seasonal weather forecasts at least once per year on average and incur an average cost of US$2 per trip. Given this expenditure, the average number of trips, and farmers using the forecasts, the total economic value of US$580 per year was estimated for indigenous seasonal weather forecasts. Just like in Benin, the findings of this study confirm that indigenous seasonal weather forecasts are valuable services [7]. It is therefore important to integrate indigenous seasonal weather forecasts into national seasonal weather forecasting and disaster risk reduction systems.

3.4.2. Factors Affecting the Number of Trips to the Source of Indigenous Seasonal Weather Forecasts

The results of the semi-log model indicated that the model fits the data well as indicated by a significant F-test and hence statistical inferences can be made from the model [42]. The R-squared value of 0.54 further showed that 54% variation in the dependent variable (visiting frequency to the source of indigenous seasonal weather forecasts) was explained by the independent variables. This R-squared value is high enough to make statistical inferences, especially given the cross-sectional nature of the data, as suggested by several researchers [47, 48]. The VIF and Tolerance values indicated the absence of multicollinearity (refer to **Table 6**). The high VIF and low Tolerance values for age and age square are due to the direct relationship between the two variables. However, the mean VIF of 7.65 indicated that multicollinearity is not a problem in the model and hence makes it possible to make statistical inferences. A total of five (5) factors were found to affect the number

Table 5. Use of Indigenous Seasonal Weather Forecasts.

Variables Definition	Variable Description	Percentage
Use of Indigenous Weather Forecasts		
Use		
Use of Indigenous weather forecasts	1 if the farmer uses Indigenous weather forecasts and 0, otherwise	58%
Actions implemented based on Indigenous weather forecasts		
Select suitable maize varieties	1 if the farmer uses Indigenous weather forecasts to select suitable maize seeds and 0, otherwise	48%
Scheduling planting dates	1 if the farmer uses Indigenous weather forecasts to schedule planting dates and 0, otherwise	36%
Scheduling land preparation dates	1 if the farmer uses Indigenous weather forecasts to schedule land preparation and 0, otherwise	21%
Reduce area under maize production	1 if the farmer uses Indigenous weather forecasts to reduce the area under maize and 0, otherwise	7%
Scheduling fertilizer application	1 if the farmer uses Indigenous weather forecasts to schedule fertilizer application and 0, otherwise	1.2%
Increase area under maize production	1 if the farmer uses Indigenous weather forecasts to increase the area under maize and 0, otherwise	0.6%
Scheduling lab our hiring	1 if the farmer uses Indigenous weather forecasts to schedule labor hiring and 0, otherwise	0.2%
Scheduling harvesting dates	1 if the farmer uses Indigenous weather forecasts to schedule harvesting dates and 0, otherwise	0.2%

Source: Survey data, 2024.

of trips to the source of indigenous seasonal weather forecasts. As expected, the cost associated with traveling to the source of indigenous seasonal weather forecasts is negatively associated with the number of trips (**Table 6**). An increase in travel costs by US$1 results in a decline in the number of trips to the source of indigenous seasonal weather forecasts by 32.3% (derived from the exponential of the parameter estimate in **Table 6** (0.28) minus 1) ($p < 0.01$). This also aligns with the Marshallian law of demand, as the price of a good or service increases (travel costs) the quantity demanded declines (number of trips). As in environmental service valuation through travel cost analysis, as the costs increase the number of trips to the source of Indigenous seasonal weather forecasts decreases [39]. Being a small-scale commercial maize farmer also negatively affects the number of trips frequency to the source of Indigenous seasonal weather forecasts, possibly due to the relatively low level of risk associated with small-scale commercial farming. The number of trips to the source of Indigenous seasonal weather forecast also reduces if a farmer is in a low rainfall region as compared to those in regions characterized by high rainfall amounts. The plausible reason here is that maize production in low rainfall regions is low hence farmers do not actively seek indigenous seasonal weather forecasts for maize production. On the other hand, as the distance to the nearest town increases, the number of trips to the source of indigenous seasonal weather forecasts increases. As the distance away from the town increases by one kilometer, the number of trips to seek indigenous seasonal weather forecasts increases by 1.1% ($p < 0.05$). This result suggests that farmers residing in remote rural areas with limited access to modern weather and climate services

Table 6. Factors affecting number of trips.

Variable	Marginal Effects	Robust St. Err.	VIF	Tolerance
Dependent Variable: Total Number of Trips Per year (in Log Form)				
Cost (continuous)	−0.28	0.09***	1.231	0.813
Perceiving climate change (1-yes, 0 otherwise)	0.002	0.24	1.112	0.899
Small-scale commercial farming (1-yes, 0 otherwise)	−0.48	0.18***	2.102	0.476
Access to extension services (1-yes, 0 otherwise)	0.14	0.15	1.321	0.757
Member of a farming group (1-yes, 0 otherwise)	−0.07	0.12	1.364	0.733
Distance to the nearest town in kilometers (continuous)	0.09	0.004**	1.629	0.614
Sex of household head (1 male, 0 female)	−0.09	0.09	1.194	0.838
Subscribe to African Traditional Religions (1-yes, 0 otherwise)	0.34	0.13**	1.179	0.848
Years of education (continuous)	0.01	0.01	1.439	0.695
Years of maize farming experience (continuous)	0.001	0.01	1.739	0.575
Farmer's age (continuous)	−0.02	0.02	50.807	0.02
Farmer's age squared (continuous)	0.00	0.00	49.848	0.02
Belong to the Ndau ethnic group (1-yes, 0 Manyika)	−0.05	0.13	1.804	0.554
Low rainfall regions (1-yes, 0 otherwise)	−0.29	0.13**	2.119	0.472
Monthly household income in US$ (continuous)	−0.001	0.001	1.53	0.653
Total land size in hectares (continuous)	0.06	0.03	1.991	0.502
Constant	1.28	0.57**		
Mean dependent variable	0.371	SD dependent variable	0.795	Mean VIF =7.65
R-squared	0.535	Number of observations	180	
F-test	26.278	Prob > F	0.000	
Akaike crit. (AIC)	323.460	Bayesian crit. (BIC)	377.740	

*** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Survey data, 2024.

are actively seeking weather forecasts from indigenous weather forecast sources; further, this result is consistent with some findings in the literature [14, 23].

The number of trips to the source of Indigenous seasonal weather forecasts also increases if a farmer subscribes to African Traditional Religions (ATR). The frequency of visiting sources of indigenous seasonal weather forecasts increases by 34% among farmers who subscribe to ATR. This is probably because farmers who subscribe to ATR understand the importance of indigenous seasonal weather forecasts compared to Christians. As a result, farmers who subscribe to ATR are more likely to seek indigenous seasonal weather forecasts compared to their Christian counterparts. Similar findings have been noted in the literature where farmers who subscribe to ATR are more likely to use indigenous weather forecasts as compared to Christians [19, 25, 46].

3.4.3. Consumer Surplus Accruing from the Use of Indigenous Weather Forecasts

Based on equation (11) and given that the coefficient of cost is negative 0.28, the consumer surplus accruing to farmers is estimated at US$3.6 per trip. This consumer surplus per trip is equivalent to annual consumer surplus per farmer given an average of a single trip per year to the source of indigenous seasonal weather forecasts. Multiplying per trip consumer surplus by the average number of trips per year gives an average consumer surplus of US$1,044 per year among 290 farmers who use indigenous seasonal weather forecasts. This result shows that maize farmers gain more economic benefits from accessing indigenous seasonal weather forecasts than the cost of visiting the source of forecast information. This also concurs with other previous studies which showed that the use of indigenous weather forecasts presents significant economic benefits to farmers [7, 24, 45]. For example, in Benin, the income of maize farmers was estimated to increase by at least 3% due to the use of indigenous seasonal weather forecasts [7].

4. Conclusions

This study examined the economic benefits and uses of indigenous seasonal weather forecasts in Zimbabwe. A significant proportion of farmers (58%) use indigenous seasonal weather forecasts to make maize farming decisions such as the selection of suitable varieties. The main indicators used for Indigenous seasonal weather forecasts are the flowering and fruition of specific trees, the behavior of certain birds, and high temperatures at night. Farmers accessed the indigenous seasonal weather forecasts by visiting the sources mainly the elders in the village and religious leaders. An average consumer surplus of US$1,044 per year among 290 farmers who use indigenous seasonal weather forecasts was estimated.

To the best of our knowledge, this study is the first attempt to estimate the economic value of indigenous seasonal weather forecasts in Southern Africa and Zimbabwe, in particular. The study is also novel in its use of a multi-purpose visit scenario to establish the benefits of indigenous seasonal weather forecasts. Thus, it presents a realistic and useful case to place indigenous seasonal weather forecasts at the center of the climate change adaptation agenda and to integrate them into national weather forecasting and disaster risk reduction systems to complement modern seasonal weather forecasts. Co-production of seasonal weather forecasts which allows participatory interactions between meteorologists, farmers, and other stakeholders to tailor forecast information to meet the needs of farmers is proposed in this regard. Apart from integrating indigenous weather forecasts into national weather forecast systems, the co-production of seasonal weather forecasts with farmers enhances their understanding, use, and trust. This further calls for the need to document and disseminate indigenous seasonal weather forecast indicators to a wider audience to increase their use. Digital documentation and dissemination through audio, videos, and other visual formats are instrumental in bridging the generational knowledge gap and strengthening awareness and use of indigenous weather forecasts among the youth.

Author Contributions

Authors Conceptualization: J.M. and K.A.A.; Data curation: J.M. and K.A.A.; Methodology: J.M. and K.A.A.; Data Analysis: J.M.; Supervision: K.A.A., A.M.-B. and A.B.; Validation: K.A.A., A.M.-B. and A.B.; Visualization: J.M., K.A.A., A.M.-B. and A.B.; Writing Original Draft: J.M.; Writing—Review and Editing: K.A.A., A.M.-B. and A.B.

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Data Availability Statement

The data used in this study is available upon request from the corresponding author.

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Conflict of Interest

The authors declare no conflict of interest.

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