



Systematic Review

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Marcellus Mbah <sup>1,\*</sup> , Sandra Ajaps <sup>1</sup>  and Petra Molthan-Hill <sup>2</sup> <sup>1</sup> Institute of Education, Nottingham Trent University, Nottingham NG11 8NS, UK; sandra.ajaps@ntu.ac.uk<sup>2</sup> Business School, Nottingham Trent University, Nottingham NG1 4FQ, UK; petra.molthan-hill@ntu.ac.uk

\* Correspondence: marcellus.mbah@ntu.ac.uk; Tel.: +44-(0)115-848-3794



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**Abstract:** Countries in the developing world are increasingly vulnerable to climate change effects and have a lesser capacity to adapt. Consideration can be given to their indigenous knowledge systems for an integrated approach to education, one which is more holistic and applicable to their context. This paper presents a systematic review of the indigenous knowledge systems (IKSs) deployed for climate change adaptation in the developing world and advances implications for climate change education. A set of inclusion criteria was used to screen publications derived from two databases and grey literature searches, and a total of 39 articles constituted the final selection. Postcolonial theory's lens was applied to the review of the selected publications to highlight indigenous people's agency, despite IKSs' marginalization through colonial encounters and the ensuing epistemic violence. The categories of social adaptation, structural adaptation, and institutional adaptation emerged from the IKS-based climate change adaptation strategies described in the articles, with social adaptation being the most recurrent. We discussed how these strategies can be employed to decolonise climate change education through critical, place-based, participatory, and holistic methodologies. The potential outcome of this is a more relatable and effective climate change education in a developing world context.

**Keywords:** climate change adaptation; indigenous knowledge systems; developing world; climate change education

## 1. Introduction

The developing world is believed to be more susceptible to the impacts of climate change, with varying degrees of vulnerability, due to its dependence on agriculture and other climate-sensitive sectors [1]. Although the term 'developing world' is problematic, it is used here for convenience and as described by the World Bank to denote countries with low or middle gross national income per capita, in contrast to the high income of the developed world [2]. Far from being homogenous, the developing world has a wide range of dissimilarities, and we focused on the continents of Africa, Asia, South America, and Oceania, where the majority of low- and middle-income countries are located. Despite being more vulnerable, the countries of the developing world have lesser capacities to adapt to climate change, especially in terms of structural and institutional adaptation strategies, due to their limited resources [1]. Here, climate change adaptation refers to the process through which people reduce the adverse effects of climate change on their health and wellbeing and take advantage of the opportunities that their climatic environment provides [3].

People in the developing world have been adapting to climate change using their indigenous knowledge systems (IKSs), which refer to cultural, traditional, and local knowl-

edge that is unique to a specific society or culture [4] and encompasses skills and technology derived from systems of production and consumption [5]. IKS is also fundamentally relational, linked to the land, language, and intergenerational transmission of songs, ceremonies, protocols, and ways of life [6]. Drawing on UNESCO, this form of knowledge system is underpinned by “understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. This knowledge is integral to a cultural complex that also encompasses language, systems of classification, resource use practices, social interactions, ritual and spirituality. These unique ways of knowing are important facets of the world’s cultural diversity, and provide a foundation for locally-appropriate sustainable development” [7] (p. 1). In addition, IKS is a crucial part of the solution to climate change, with respect to mitigation and adaptation [8]. Yet, despite the increasing knowledge of the significance of IKS, we do not have a sufficient knowledge database about how IKS is being deployed for climate change adaptation, as well as answers to related questions such as what IKS is being deployed, where, why, for whom, and by whom. This systematic review responds to this knowledge gap by analysing a range of relevant articles to provide answers to these questions and to discuss their implications for climate change education.

We argue that the integration of IKS-based climate change adaptation strategies with the scientific knowledge already established in the formal education systems of developing world contexts is necessary for the decolonisation of climate change education. Majority of the countries in the developing world were previously colonised and with the imposition of Western knowledge systems, colonialism violently disrupted relational ways, dismantled relational worldviews, and marginalised indigenous ways of knowing [6]. In her postcolonial theory, Spivak [9] (p. 77) described this destruction of non-Western ways of perceiving the world and the resultant dominance of western ways as ‘*epistemic violence*’—the infliction of harm against subjects through discourse. This explains the prevalent finding that IKS for climate change adaptation is disappearing among indigenous people [10–12], and analyses of the reasons for this problem rarely move beyond ‘modernisation’, ‘indigenous knowledge is transmitted orally’, ‘elders are dying’, etc. This simplistic analysis neither explains why IKS became threatened in the first place nor values the rigour indigenous knowledge holders have employed for centuries to transfer environmental knowledge to younger generations [13]. Thus, a postcolonial lens is useful for analysing and transforming climate change education through the critical analysis of IKSs’ vulnerability and rapid extinction. This begins with understanding IKS-based climate change adaptation and its encounter with colonial and hegemonic knowledge systems and then progresses to the transformation of climate change education by integrating the marginalised IKS with the existing educational system, as discussed later in this paper.

Recently, researchers are focusing more on IKS-based climate change adaptation, undoubtedly because the Paris Agreement recognised indigenous people and their traditional system as part of the solution to climate change, and this insight is valuable to foster adaptation and resilience during calamities [14]. Additionally, the 2015 sustainable development goals agreed upon by the international community specifically acknowledged that there can be no truly sustainable development without protecting the traditional knowledge and territories of indigenous people [15]. Despite the proliferation of studies on indigenous adaptation strategies for climate change, syntheses of this information are limited. Indeed, reviews of climate change adaptation in the developing world exist, but only a few have considered indigenous knowledge systems. For example, [16] discussed the status of climate change adaptation in Africa and Asia while [17] provided a global evidence map of indigenous knowledge’s deployment to climate change adaptation. The former requires updating while the latter requires more in-depth focus on countries in the developing world because of their unique context, which includes their higher vulnerability to climate change and lesser capacity to adapt to its impact.

Therefore, the main purpose of this paper is to systematically review the deployment of IKS towards climate change adaptation in the developing world context, towards

providing answers to the following questions: What are the drivers of IKS-based climate change adaptation in the developing world? What IKS is being deployed and what are the outcomes? Who is deploying IKS and for whom? What are the implications for climate change education? The method employed to answer these questions is described in the ensuing section.

## 2. Method

### 2.1. Data Extraction

Articles for this systematic review were derived from two databases—Web of Science and ProQuest—and other sources such as reference lists and google searches for more relevant articles and grey literature. Web of Science was chosen because it is a broad database that is considered accurate and reproducible and used by official organisations and most researchers as the standard. It is also the world's leading scientific citation search and analytical information platform. ProQuest was chosen because, being a database of databases, it is more encompassing than Web of Science, indexes majority of articles published on IKS deployment towards climate change adaptation in the developing world and supports very focused search that brings up directly relevant articles.

We focused on peer-reviewed journal articles between the years 2010 and 2020 that were available in English language and full text. These criteria were applied to limit the scope of the study with respect to available resources and for the following reasons. The Paris Agreement [8], in Article 7 Paragraph 5, recognises that indigenous knowledge has a role to play in climate change adaptation actions, and it is expected that this has incited research on the topic since 2015. Thus, the initial consideration was to start from 2015. However, even though most of the articles were post-2015 as predicted, there were some relevant articles pre-2015 (see Web of Science analytics extract in Appendix A). Therefore, the 11-year range (1 January 2010 to 31 December 2020) provided a richer set of data for analysis because it contained pertinent IKS-based climate change adaptation knowledge that could enrich climate change education and improve the developing world's adaptive capacity. Furthermore, the search was restricted to English language so that translations were not required.

Search terms employed were indigenous knowledge, local knowledge, traditional knowledge or local ecological knowledge, and climat\* change adapt\*, global warming adapt\*, or climat\* varia\*, and developing world or third world or developing countr\*. Titles and abstracts were searched on Web of Science and ProQuest on 16 February 2021. The search procedure, including search terms and inclusion and exclusion criteria, is documented in the appended Appendix A. The combined hit of 4150 references was downloaded into RIS files from the two databases and uploaded on EndNote Online for screening, where duplicate references were found and removed using the Organize tool. References were then screened in three stages. Stage 1 comprised screening of titles; however, when it was not very obvious where a title should be grouped, its abstract was quickly scanned for group assignment. Stage 2 comprised screening of abstracts, and Stage 3 comprised screening of full-text articles. These are shown in the PRISMA Flow diagram in Figure 1. Ten additional publications were found through references of selected articles and Google search. An overview of the 39 articles included in this review is presented in Supplementary Table S1.

### 2.2. Analysis

Data were entered into the SPSS software to generate descriptive statistics that summarize trends in the publications, and inferential statistics were not viable due to cell counts ( $n = 39$ ). A summary of the data is provided in Supplementary Table S2. With quantitative analysis, clear pictures of the data can be presented, but the risk of distorting the original data or losing important detail is high [18]. Thus, we combined this method of data analysis with qualitative analysis, which was performed by identifying key themes in the publications that were related to our research questions and applying thematic codes to

categorize them. This required reading all the articles first, to discover relevant themes and create coding categories [19]. Then all the articles were read again, with applicable codes assigned to sections of texts. The research questions were then answered by evaluating the coded text together with the quantitative analysis, and the results are presented below.

### PRISMA 2009 Flow Diagram

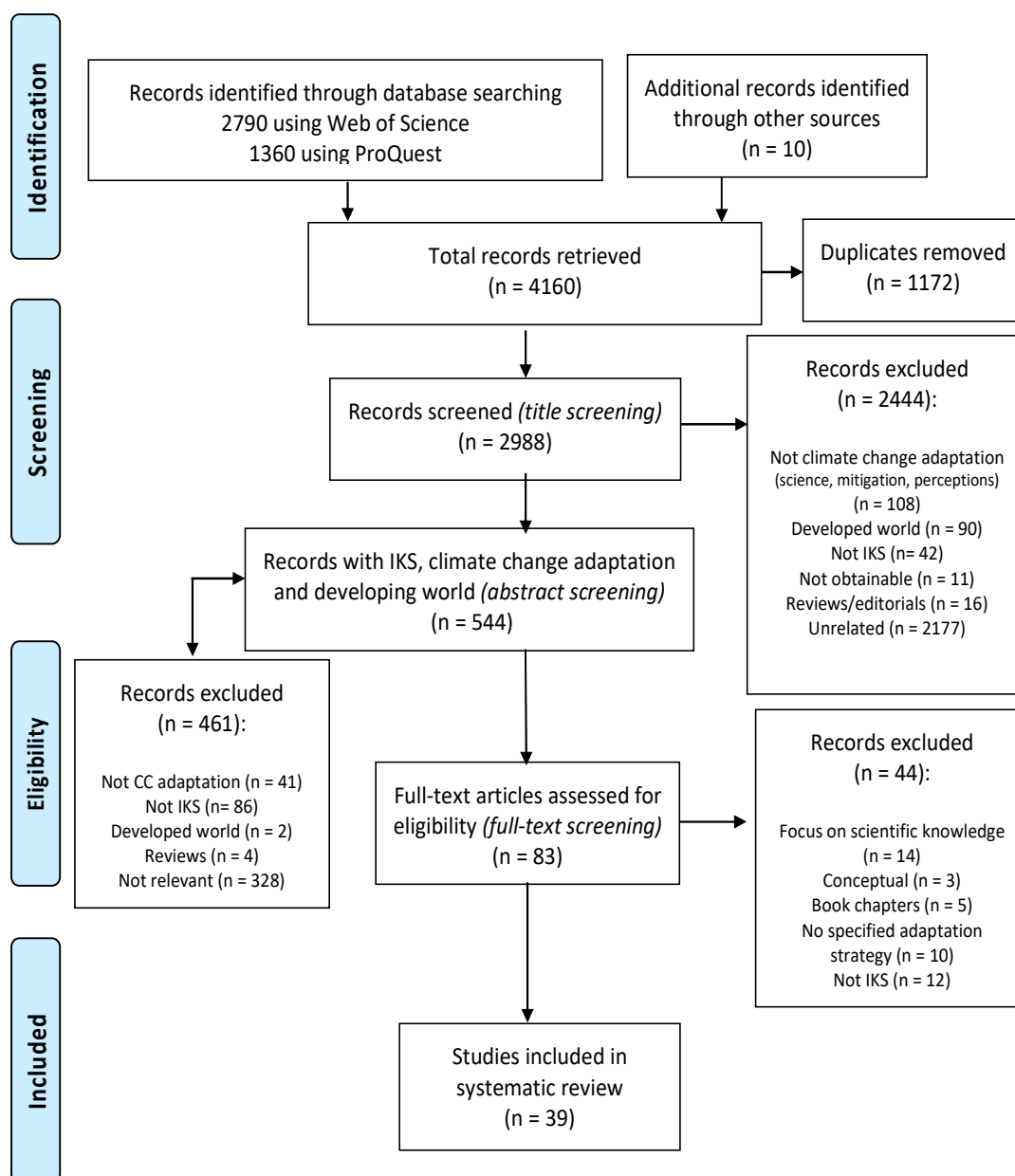


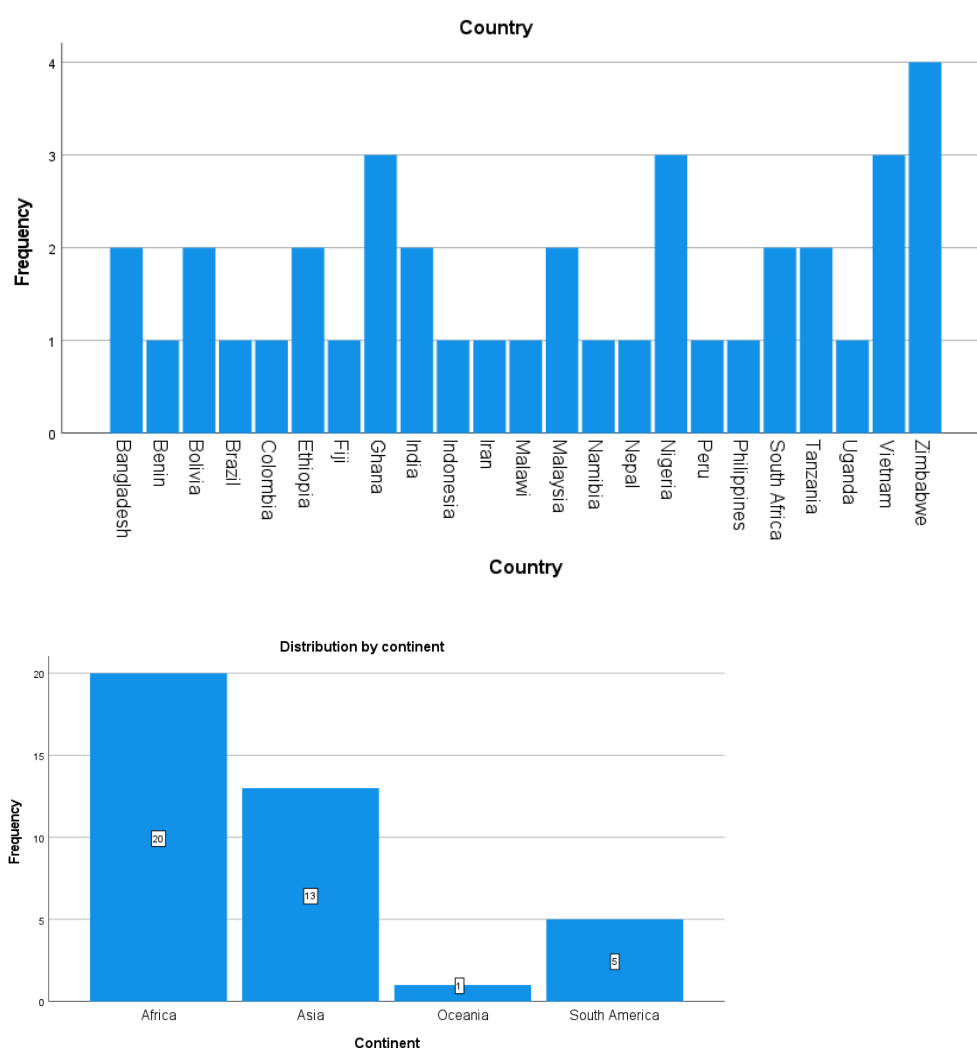
Figure 1. Systematic review process.

### 3. Evidence Synthesis: Description of Research on IKS Deployment to Climate Change Adaptation in the Developing World

#### 3.1. Overview of the Reviewed Articles

Despite the heterogeneity of the developing world, with some countries having higher gross national incomes and less vulnerability to climate change, there was no significant systematic difference in the IKS-based adaptation strategies reported. A description of the

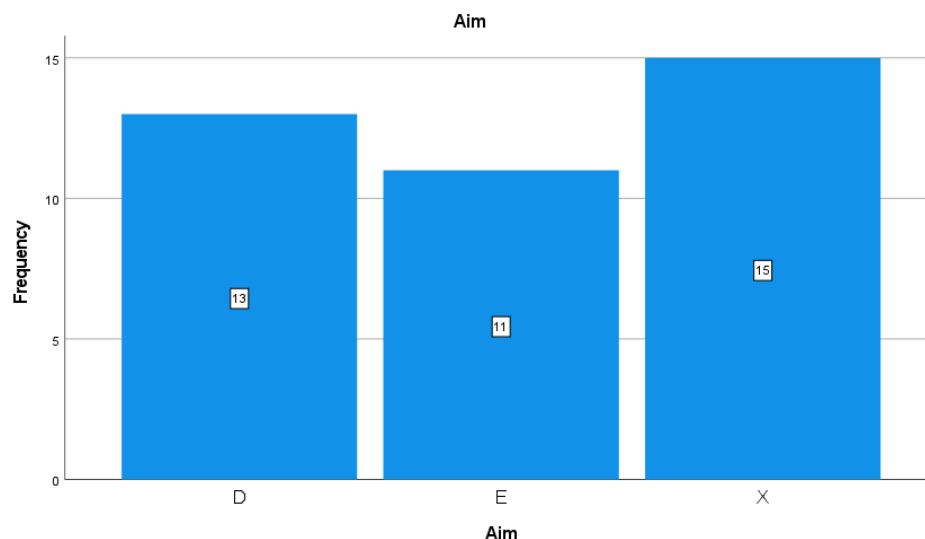
39 articles included in this systematic review is presented here, with more details available in Supplementary Table S2. Published IKS-based adaptation strategies in developing world context are predominantly from the African and Asian continents, with only a few from South America and Oceania (Figure 2). This reflects the documented geographical gap in IKS-based climate change adaptation research found in other systematic reviews, with northern and central Africa, northern Asia, South America, Greenland, and Australia being underrepresented while the research clusters around Sub-Saharan East Africa, the Tibetan plateau, and the North American Arctic [17,20,21]. For example, of the 236 articles reviewed in their global evidence map paper that had a broader scope than this current systematic review, 92 were from Africa, 75 from Asia, 31 from Australasia and small island states, 26 from North America, and 12 from Central and South America [17].



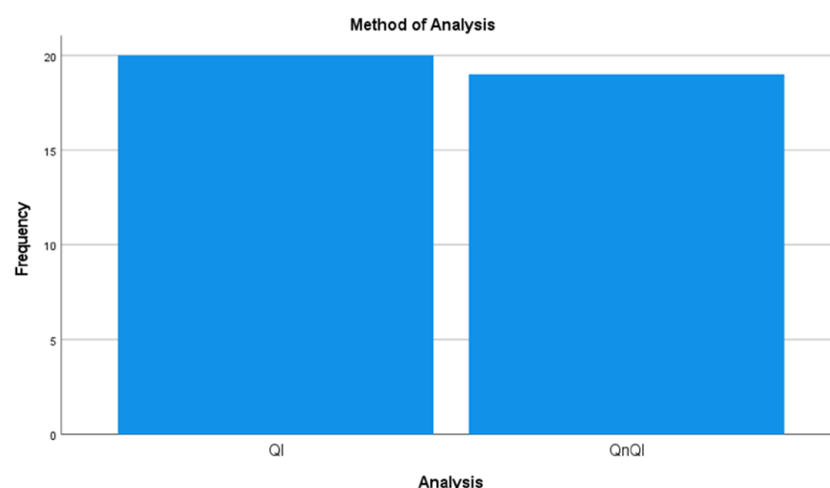
**Figure 2.** Distribution by country and continent.

Furthermore, as shown in Figure 3, the stated aims or objectives of the publications can be categorised as descriptive (e.g., describe, document, identify), explanatory (e.g., explain, determine, demonstrate), and evaluative (e.g., evaluate, analyse, assess). The predominance of the combination of descriptive and explanatory objectives, especially, reveals that researchers are mostly presenting the information derived from indigenous people without imposing their own knowledge, thereby centring indigenous people in the research process. Correspondingly, the type of analysis usually employed by research on IKS-based adaptation strategies is qualitative, where research participants' words and their meaning are analysed without generalisations. No purely quantitative study was found

(Figure 4), and even where studies employed mixed methods, qualitative and quantitative, the latter is usually descriptive statistics derived from structured interviews or surveys and analysed qualitatively.



**Figure 3.** Categorisation of publications' objectives. D = Descriptive; E = Evaluative; X = Explanatory.



**Figure 4.** Type of analysis. QI = Qualitative method; QnQI = Mix of quantitative and qualitative methods.

As shown in Figure 5, interview as a data source was employed by most of the reviewed articles ( $n = 36$ ), with focus group discussions following closely ( $n = 28$ ). The combination of interviews, surveys, and focus group discussions had a significant frequency ( $n = 15$ ). This reveals the intensity of interactions and discourse involved in understanding IKS and their deployment to climate change adaptation, and it is important to derive the knowledge directly from indigenous people. Focus group discussions were usually divided by gender and age because of cultural norms whereby women and youths may find it hard to express themselves in the presence of men and elders, respectively [22,23]. Walshe's [24] preparatory trip also showed that women were more forthcoming when not in the presence of men.

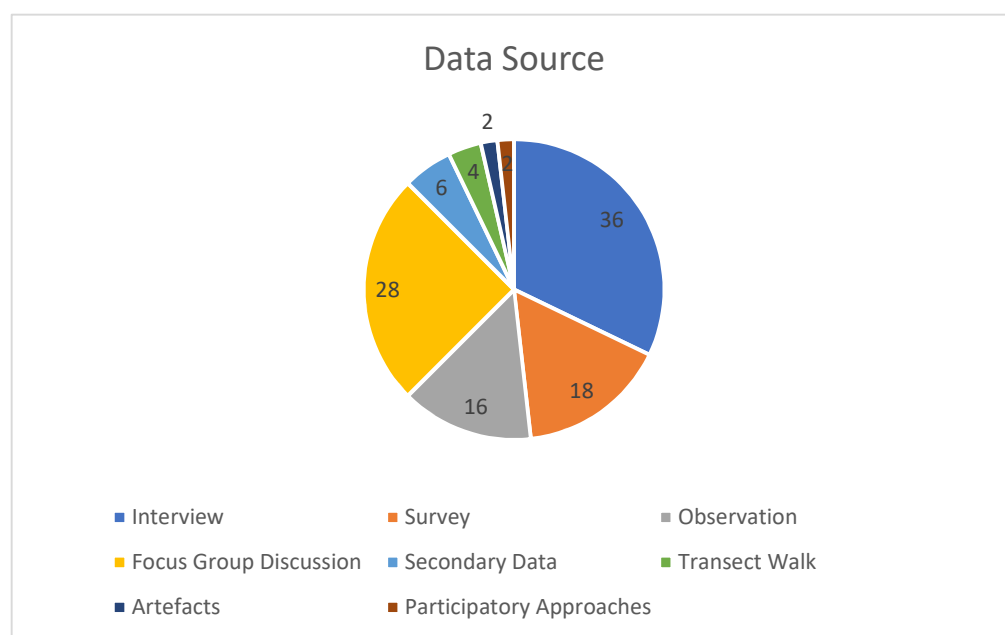


Figure 5. Data source.

Indigenous Knowledge was the most commonly used term, employed by 22 of the 39 articles reviewed (Figure 6). Traditional Ecological Knowledge was used by three articles, and other terms were used by either one or two articles. Varying definitions of these terms were provided by most of the authors, and they all referred to the knowledge held by indigenous people.

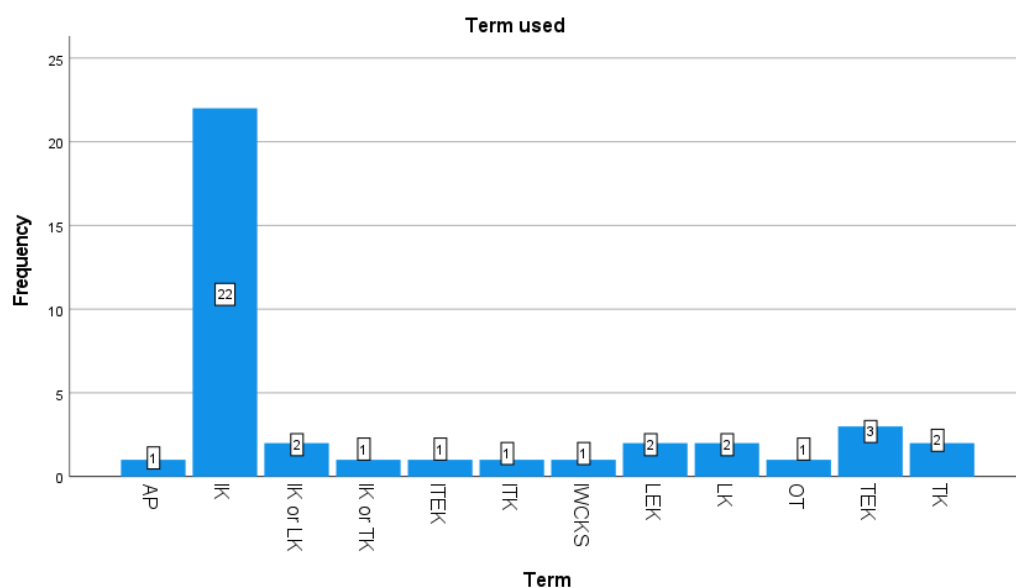
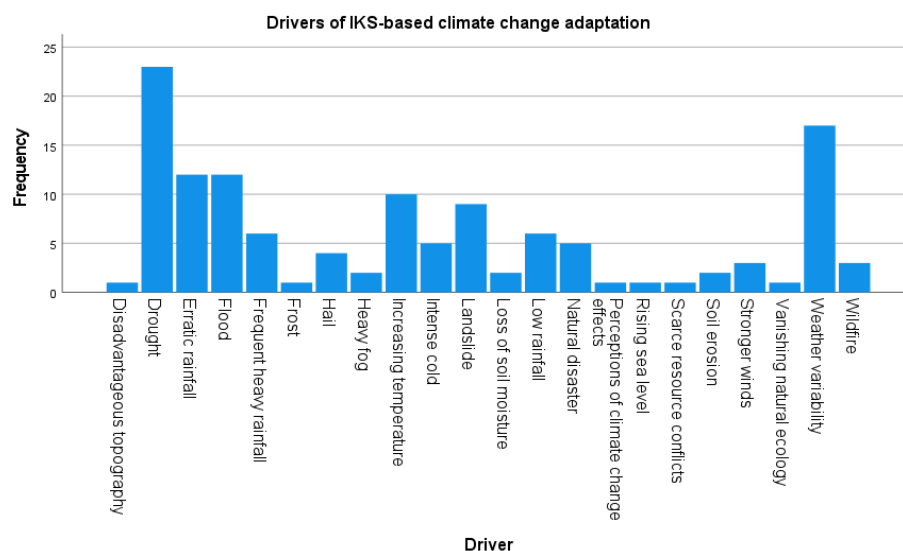


Figure 6. Terms used to denote IKS. Terms: AP = Asset Portfolio; IK = Indigenous Knowledge; LK = Local Knowledge; TK = Traditional Knowledge; ITEK = Indigenous Traditional Ecological Knowledge; ITK = Indigenous Technological Knowledge; IWCKS = Indigenous Weather and Climate Knowledge System; LEK = Local Ecological Knowledge; OT = Oral Traditions; TEK = Traditional Ecological Knowledge.

### 3.2. Drivers of IKS-Based Climate Change Adaptation in the Developing World

Drought was the most frequent driver of IKS-based climate change adaptation in the reviewed articles, with its mention in 23 of the 39 articles (Figure 7). Weather variability

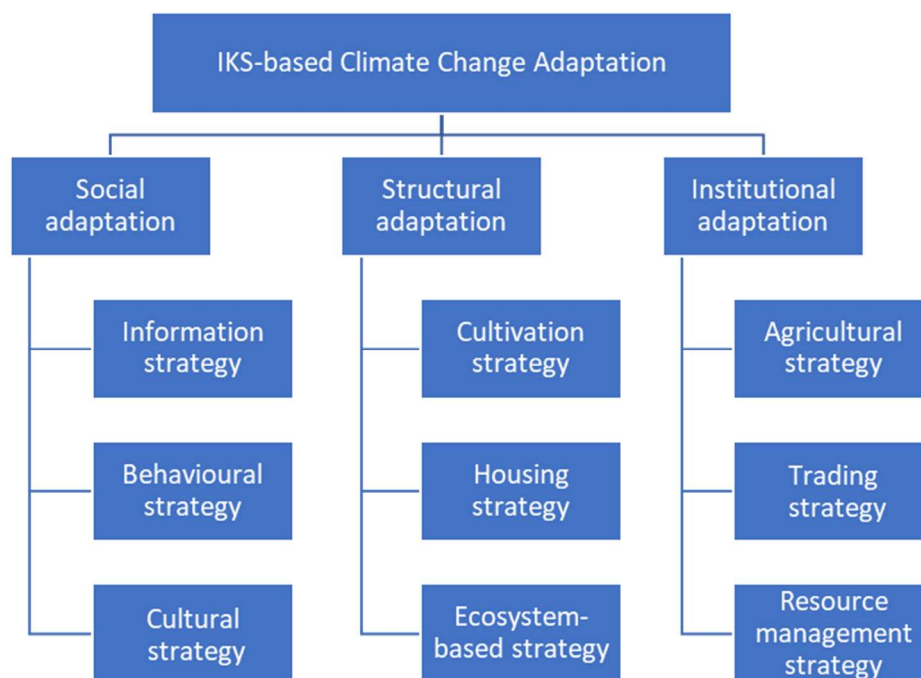
also had a high frequency of occurrence ( $n = 17$ ), and even though this includes variations in temperature, rainfall, and wind, it was categorised separately to maintain the words used by the authors. This is similar to natural disaster ( $n = 5$ ) mentioned separately from landslide ( $n = 8$ ), wildfire ( $n = 3$ ), and flood ( $n = 12$ ). The distribution of these adaptation drivers is similar to Petzold et al.'s [17] findings.



**Figure 7.** Drivers of IKS-based climate change adaptation.

### 3.3. Nature of IKS Deployment to Climate Change Adaptation

The IKS-based climate change adaptation strategies described in the reviewed articles were categorised here as social adaptation, structural adaptation, and institutional adaptation, as framed by Noble et al. [1] in IPCC's AR5, and summarised in Figure 8.



**Figure 8.** IKS-based climate change adaptation strategies.

### 3.3.1. Social Adaptation

This refers to adaptation strategies that include information, behavioural, and cultural components, as discussed below.

#### Information Strategy

##### *Weather forecasting*

A prevalent adaptation strategy employed by many indigenous people is the use of astronomical, meteorological, biological, and supernatural indicators to predict weather, as summarised in Table 1. Flora and fauna indicators are the most widely used. For example, excessive fruiting of plants such as mango and palm trees predicts drought in the upcoming season, while ants seeking shelter within structures indicate onset of heavy rains within two or three days. The moon is also an important indicator, with its shape, position, and colour determining the volume and timing of rainfall, if any. In addition, there has been film and literature documentations of the indigenous art of rainmaking, where communities know that rain will fall when diviners or rainmakers perform the rainmaking rituals [11,25]. Diviners also control strong winds and hold off rains especially for important ceremonies [26].

**Table 1.** Weather forecasting indicators and their significance.

| Indicator      |             | Significance [And Citations] |                                                                                                                                 |
|----------------|-------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Astronomical   | Sun         | i.                           | Halo around the sun indicates storm, erratic rains and cyclones [12]                                                            |
|                |             | ii.                          | Red sunset indicates humidity [27]                                                                                              |
|                |             | iii.                         | Positioned in the southwest during the rainfall season signifies imminent rain [28]                                             |
|                | Moon        | i.                           | Sideways position of the moon signals the coming of food scarcity [29]                                                          |
|                |             | ii.                          | Very white full moon means rain is likely [30]                                                                                  |
|                |             | iii.                         | Moon phase (onset of rain by observing the shape of crescent) [12]                                                              |
|                |             | iv.                          | Yellow moon indicates a lot of rain [27]                                                                                        |
|                |             | v.                           | Halo of light around moon forecasts rain [28]                                                                                   |
|                |             | vi.                          | Oval shape with small black spot in middle indicates good rainfall season [28]                                                  |
|                |             | vii.                         | White moon indicates low rainfall [28]                                                                                          |
|                |             | viii.                        | Half-moon facing the east means no rain to come [4]                                                                             |
|                |             | ix.                          | Downward crescent shape means high rainfall within the next few days [4]                                                        |
|                |             | x.                           | Full moon without tilt indicates drought and dry spells [4]                                                                     |
|                | Star        | i.                           | Morning star seen for 240 days without eclipse means lack of rain in the coming season [30]                                     |
|                |             | ii.                          | Star constellations (directs fishers towards fishing ground [12]                                                                |
|                |             | iii.                         | Arrival of the star qoto (inca constellation) represents the time to start planting [27]                                        |
|                |             | iv.                          | Early emergence of nangakavuji star in mid-november in the west as it moves from the east signifies a good rainfall season [28] |
|                |             | v.                           | Five groups of stars called malhino emerge in the east during early morning indicates rains in a week or two [31]               |
| Meteorological | Cloud       | i.                           | Dark clouds preceding strong winds means rainfall in a few hours [10]                                                           |
|                |             | ii.                          | Dark clouds indicate heavy rainfall within a few hours [30]                                                                     |
|                |             | iii.                         | Fog and cloud during june and august indicate wet year [27]                                                                     |
|                |             | iv.                          | Appearance of dark clouds signifies rain coming within the next few hours [4]                                                   |
|                | Rain        | i.                           | Low summer rains mean warmer winter [4]                                                                                         |
|                |             | ii.                          | High summer rains mean cold winter [4]                                                                                          |
|                | Temperature | i.                           | Relatively high winter temperatures or low temperatures during August-October predicts poor season [32]                         |
|                |             | ii.                          | Cold temperatures indicate low rainfall in next season [4]                                                                      |
|                |             | iii.                         | Extended cold winter means drought is coming [30]                                                                               |
|                |             | iv.                          | High temperature from September to November signifies onset of rainfall [28]                                                    |
|                |             | v.                           | Very high temperature by mid-November predicts drought [22]                                                                     |
|                |             | vi.                          | High temperature means heavy rains coming next season [4]                                                                       |

Table 1. Cont.

| Indicator    |               | Significance [And Citations] |                                                                                                                                                                                                                                             |
|--------------|---------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|              | Wind          | i.                           | North winds indicate high rains in next season [4]                                                                                                                                                                                          |
|              |               | ii.                          | Wind and tidal patterns signal fish harvesting and gear operation [12]                                                                                                                                                                      |
|              |               | iii.                         | Wind movement identifies the directions for gear operations [12]                                                                                                                                                                            |
|              |               | iv.                          | wind from northeast brings the rain [27]                                                                                                                                                                                                    |
|              |               | v.                           | Strong winds before an impending rain event previously meant no rains but now means stormy rains [22]                                                                                                                                       |
|              | Water surface | i.                           | Warm surface water indicates fish abundance [12]                                                                                                                                                                                            |
|              |               | ii.                          | Bubbles in the water surface indicates storm and sometimes specific fish shoals [12]                                                                                                                                                        |
|              | Rainbow       | i.                           | Long-standing rainbow means long rainy season likely [30]                                                                                                                                                                                   |
| Biological   | Flora         | i.                           | Heavy fruiting of mupfura tree indicates imminent drought in the coming rainy season [10]                                                                                                                                                   |
|              |               | ii.                          | Profuse fruiting of muhacha and mukwakwa trees is main indicator for a poor season [32]                                                                                                                                                     |
|              |               | iii.                         | Dry spell is imminent if extra bushy acacia trees are observed [33]                                                                                                                                                                         |
|              |               | iv.                          | Abundance of mango fruits as indicator of drought in upcoming season [4]                                                                                                                                                                    |
|              |               | v.                           | Dropping of fruits before maturity means drought is expected [30]                                                                                                                                                                           |
|              |               | vi.                          | Excessive fruiting of breadfruit and mandarin signals the approach of extreme weather [34]                                                                                                                                                  |
|              |               | vii.                         | Flowering patterns of duraznero indicate time of rainy season; pilli pilli grows in moist soil, not good for potato crop and very difficult to till; layo grows in areas where the soil has very good quality that is ideal for potato [27] |
|              |               | viii.                        | Shedding of leaves by some tree species like baobab and mtondo indicates onset of well distributed rainfall season [22]                                                                                                                     |
|              |               | ix.                          | Blooming of certain trees like eepto and tikibleyta signifies upcoming rain [31]                                                                                                                                                            |
|              |               | x.                           | Gersa tree turns from dull grey to deep green, produces more shoots, fruits and seeds indicates drought in the next season [31]                                                                                                             |
|              |               | xi.                          | Alternating size of banana buds and moisture content of grasses indicate windstorm [35]                                                                                                                                                     |
|              |               | xii.                         | Palm trees bearing more than a typical amount of fruit indicate drought over the next year [35]                                                                                                                                             |
|              |               | xiii.                        | Decreasing lustre of trao leaves indicate impending floods [35]                                                                                                                                                                             |
|              | Fauna         | i.                           | If the White frog that stays on trees croaks in summer, it indicates onset of rains [10]                                                                                                                                                    |
|              |               | ii.                          | Presence of many fireflies on the biri tree signals that floods and landslides may occur [29]                                                                                                                                               |
|              |               | iii.                         | Peculiar sound produced by male goat indicates onset of rains [22]                                                                                                                                                                          |
|              |               | iv.                          | Occurrence of grasshoppers and the Chinkhaka bird in household vicinity means drought [22]                                                                                                                                                  |
|              |               | v.                           | No rainfall if honeybees fly toward northern hill but good rainfall if towards southern hill [33]                                                                                                                                           |
|              |               | vi.                          | Appearance of ants and termites indicates an imminent rainfall and good season [30,33]                                                                                                                                                      |
|              |               | vii.                         | Appearance of a local bird indicative of rain coming in a day [4]                                                                                                                                                                           |
|              |               | viii.                        | Croaking of frogs was an indicator of immediate rain [4]                                                                                                                                                                                    |
|              |               | ix.                          | Turbid colour inside the intestines of animals means above normal rain/flooding [30]                                                                                                                                                        |
|              |               | x.                           | Cow returning home after grazing and not blowing to her calve predicts drought [30]                                                                                                                                                         |
|              |               | xi.                          | Stocks of cormorants, gulls and dolphins indicates fish abundance [12]                                                                                                                                                                      |
|              |               | xii.                         | Hopping sea snakes predicts cyclone [12]                                                                                                                                                                                                    |
|              |               | xiii.                        | Catching the Na Ki fish results in a large wave (tsunami) coming soon afterwards [34]                                                                                                                                                       |
|              |               | xiv.                         | Hornets building nests closer to the ground than usual is a sign that a tropical cyclone is imminent [34]                                                                                                                                   |
|              |               | xv.                          | Crying fox identifies the place for next plantation, ants flying during cloudy day announces the rain, spider webs indicate humidity in the soil [27]                                                                                       |
|              |               | xvi.                         | Ka'a insect starts stinging animals and humans indicates rains will start within a week or two [31]                                                                                                                                         |
|              |               | xvii.                        | Ants seeking shelter within structures indicate onset of heavy rains within two or three days [35]                                                                                                                                          |
|              |               | xviii.                       | Beehives situated in a low position indicates heavy rains or flooding [35]                                                                                                                                                                  |
|              | Human         | i.                           | Feeling cold during warm days is a sign to postpone planting of rice and corn [29]                                                                                                                                                          |
|              |               | ii.                          | Excessive sweating on cloudy days signifies rain in a few hours [4]                                                                                                                                                                         |
|              |               | iii.                         | Painful joints or operation scars predicts humid or cold weather by the next day [4]                                                                                                                                                        |
| Supernatural | Diviners      | i.                           | Performs rainmaking ceremony during droughts to bring rains [11]                                                                                                                                                                            |
|              |               | ii.                          | Controls strong winds [26]                                                                                                                                                                                                                  |

### *Education*

Among indigenous people, local knowledge of the environment, which includes climate change adaptation knowledge, is transmitted across generations through ceremonies and cultural festivals [14,36]. Listening to information about climate change was a prominent feature in Nzeadibe's [23] study, while training on behalf of the State to develop crops was reported by Cordoba Vargas [37].

### *Behavioural Strategy*

Farming activities, water conservation and irrigation practices, soil improvement practices, native crop varieties and animal breeds, pest and disease management, food conservation, and livelihood diversification constitute the behavioural strategies identified in the reviewed articles, as presented below.

#### *Farming activities*

##### *Planting*

Before the planting season, farmers deploy IKS to adapt to weather variability by adjusting planting calendars [29,35,38], plot fragmentation, soil management, and land preparation [10,33], tilling the land before the rains [3], and seed selection or variety selection for stress tolerance [10,27] before the planting season. To adapt to increased flooding, farmers clear their lands for planting later than before [39] and drain wetlands for crop cultivation [23].

During the planting season, farmers plant early with first rain especially for crops such as maize and cassava [23] and also plant some crops later than before [39] to adapt to a shorter rainfall period. Crop diversification, intercropping, or multiple cropping such as banana and vegetables in between rows of pineapples [5,14,22,23,35,36,38,40–43] shifting cultivation in response to increasing temperatures at lower altitudes, for example, [10,14,24,36,44], and crop rotation [29,38,42,43] are also widely employed to help spread risk across space and time. Other activities engaged during the planting season are delayed fertilizer use [10], replanting with early maturing varieties and increasing plant density when replanting [10], concentrating on planting on more wetland fields and low-lying areas than upland areas [32,45], and regular weeding of cropped farmland [23].

After planting, farmers cover fruits with banana leaves during high sunshine intensity [40], spread anthill soil to fields [10], and harvest wild fruits and wild legumes during drought periods [45]. Early harvesting [34,38,40], burning of crop residues [42], and selection and preservation of seeds for the next planting season [23] are also strategies employed to adapt to climate change.

##### *Herding*

Cattle herders adapt indigenously by temporally changing nomadic migration and adjusting mobility patterns: linear, irregular, circular, or migratory movement, dependent on ecological landscape and weather [39,46,47]. As a result of drought, they also go to rivers for water supply, dig artesian wells, and store water in ponds [39,47]. Sources of feed are also diversified: pruning of tree branches and leaves, use of crop residue, and reliance on grass sprouts in valleys resulting from dewfall [46]. Direct feeding happens more frequently [47], animals are fed with supply feed, and small seeds are mixed with hot water and salt to keep the animals warm [48].

In terms of stress management, herders focus on reducing heat among cattle by keeping them under tree shades and separating them into sub-herds based on sickness, pregnancy, lactation, or whether they are wounded, weak, and are calves [46], as well as reducing the number and changing the composition of livestock [47]. Social networks are also engaged within a community to cope with natural hazards [48], and labour activities are divided according to the sex and age of household members for meeting differential needs of herds [46]. Oviedo [39] also documented herders' enforcement of the agreement of building cattle sheds (maromba) away from the river, avoiding animal crossing through the river and lakes, and prohibiting the disposal of chemical products in the river during dry season. With specific reference to beekeeping, the IKS-based strategies employed are

protection of beehive areas, keeping of beehives under the shades of big trees, amendment of the periods of beekeeping operations, increase in the number of hives, and change of sites of hives [49].

#### *Water conservation and Irrigation practices*

Rainwater harvesting is a common practice [43,50], especially through digging ponds and deeper wells [38] and *chal*, a small water storage structure on both sides of the hill, for drinking and irrigation [33]. The storage and use of water in wells or tanks were also reported [23,33,37,40]. In addition, to manage the scarce water resource, indigenous water conservation measures [5] and water conservation techniques such as conservation agriculture [45], reliance on alternative sources of water, and increased roles of males in household water collection [50] also constitute the water conservation strategies. Indigenous people also engage irrigation practices [23,35], including the oasis farming system [33]. In David's [51] study, the people also controlled and regulated water resources (Aia adat) in an alternating night irrigation scheme.

#### *Soil improvement practices*

Mulching, the application of a layer of material such as litter or organic fertilisers to the surface of soils, was the most identified soil improvement practice in the reviewed articles [23,37,38,40,45]. Organic fertilisers or manure were also identified as a common strategy [5,23,27,41], including the use of cow-dung manure, rotten pineapple leaves [40], and charcoal from burnt trees [3]. Planting cover crops such as melon to provide shade and help conserve soil moisture [23,37,38] is also engaged by indigenous people. Other soil improvement practices among the communities in the reviewed studies are planting crops in heap [38], digging of holes for crops and the seed is covered with dry grass and water to fast-track the plant's growth [3], zero tillage [23], indigenous compost pit [33], water preservation methods to increase water holding in crumbly soils [43], and potted corpse ash buried in the farm so that the soul makes the soil fertile [40].

#### *Native crop varieties and animal breeds*

Indigenous people adapt to climate change by using native crop varieties [5,22,23,26,29,32,35,37,40–42] and native animal breeds [41,42]. They have found the native species to be more resistant to drought and other climate hazards, highly adapted to local conditions (e.g., needing less amount of water), and resilient to pests. For example, crop type change from maize to traditional millet and sorghum [3]. Indigenous people also plant early maturing crops [26], engage in biodiversity-based farming [29], and conserve and deploy agrobiodiversity by rejecting non-native breeds and collectively conserving crop diversity, sharing best practices and varieties that are resilient to climate change [24].

#### *Pest and disease management*

To manage pests and diseases in crops, livestock, and humans, indigenous people plant and use medicinal plants for curing diseases and increasing the protection of crops from wildlife [26,27,38]. For example, agbo (local herbal drink) is consumed during the rainy season to prevent malaria [52] and apple paste (indigenous paste made with diesel or linseed oil, nelathota (CuSO<sub>4</sub>), and lime) is applied to apple trees to prevent scale disease, as well as the application of wood and fly ash to vegetable fields to control pests [33]. Furthermore, invasive species are eradicated through regular slash and cleanup, [38] and houses and surroundings kept neat and tidy, along with mosquito nets to prevent mosquito bites [52]. Dietary changes are also made to protect from extreme cold, for example, fermented wheat specially prepared to keep bodies warm [33].

#### *Food conservation*

To adapt to weather variability and its associated impact on food availability, indigenous people select, store, and conserve food according to present and future needs [26,27,53], including food conservation measures such as fermentation and sun drying [43], burying to ferment 'cyclone foods' such as breadfruit and plantain [34], roasting fish for its preservation for up to five months, and storing foods such as garri (processed cassava) in airtight sacks placed on elevated wooden platforms [51]. In times of scarcity, non-traditional wild foods are consumed [29,53], including wild animals such as rabbits and mice [45]. Food

is also stored on shelves rather than on the floor to prevent decay due to dampness and mould that build up due to excessive moisture that comes with heavy rainfall [52].

#### *Livelihood diversification*

Although indigenous people depend on agriculture to a large extent, livelihood diversification is necessitated due to the declining agricultural productivity associated with climate change. Among the communities studied in the reviewed articles, indigenous people are expanding their income sources through basket weaving and handicrafts [29], intensification of livestock production especially of goats and local chicken [22], handicrafts, livestock rearing and fish farming [38], undertaking non-farming activities [26], producing coca tea and engaging in eco-tourism and cultural tours [24], off-farm jobs in nearby commercial farms [45], a combination of agro-fingerpounds and cropping dykes—diversified agriculture in flood plains during a low-water level, followed by corn cropping during the rainy season [54] and developing multiple productive activities in general [36].

#### Cultural Strategy

Belief systems and communal pooling constitute the cultural strategies employed by the communities in the reviewed articles. With regard to belief systems, tribe philosophy serves as the basis of social network that promotes social cohesion [14], including principles for resource preservation such as ‘take only what you need’ and ‘kill only enough food’ [36]. Indigenous rituals and beliefs such as creating no sound during rice harvesting because of the belief that low yield is due to too much noise produced during harvesting and getting permission from their ancestors before eating freshly harvested rice were also reported by a study in the Philippines [29]. Indigenous people also adapt to climate change through spiritual sessions, rites, and prayers to strengthen the unity of the community, village elder’s dreams, rites and other methods to prepare the community for weather extremes, etc. [26,53], and church institution promoting collective actions in responding to climate difficulties [14]. In terms of communal pooling, especially during a crisis, the church’s rice farm helps people who run out of food, and community members maintain good relationships and obligations to each other, upholding practices that strengthen community kinship and help those facing hard times [36]. Communities also unite to carry out evacuation and rescue work [29].

#### 3.3.2. Structural Adaptation

Cultivation, housing, and ecosystem-based strategies constitute the structural adaptation of the indigenous communities studied. In terms of cultivation, terracing was the most frequent strategy [27,29,33,37,38]. Other cultivation-related strategies are drainage facilities for crops [38], installing green fences, installing irrigation systems, creating new designs of agricultural beds to avoid fertilizer loss, installing drainage systems for rainwater, and making infiltration ditches [37].

Houses are also being adapted to climate change, including sheltering decisions such as where to build, prepare meals, take domestic animals during flood event; sand selection and use for protection, how and with what to build, etc. [53]. In addition, indigenous housing strategies are being engaged, such as low huts to prevent roofs being blown off during strong typhoons, building houses far away from the river [23], changing housing and staircases patterns [38], raising house foundations 1–2 m off the ground, use of concrete (instead of mud) blocks as they are more unlikely to collapse due to heavy rainfall [52], strengthening buildings [34], and making stilt houses higher and stronger; current stilts are up to 3m high and no more than 4 × 4 inches [39].

The ecosystem-based strategies include reclamation of wetlands/river valleys, contouring farmlands [23], planting more tree species surrounding the locality as shelterbelt, use of bamboo sticks to protect seedlings and saplings from windbreaks, construction and maintenance of roads and culverts [38], covering forage structure with low-cost polythene to prevent spoilage and protect forage structure from hailstorm damage [33], whedo (traditional fingerpounds) built since medieval times in flood-plains of rivers and lakes to trap the

wild fish during low-water periods [53] and levees restoration, planting of grassland and trees, and building fences [39].

### 3.3.3. Institutional Adaptation

This refers to the creation and enforcement of laws by traditional institutions, with prominent strategies reported in the agriculture, trading, and resource management sectors in the reviewed articles. With respect to agriculture, communities establish where, when, and how to cultivate [53], community nutritional gardens [45], integrated crop-animal farming [36], collective labour in sync with agrarian cycles to increase productivity during planting and harvesting [24], and pig breeding in captivity [39]. Traditional institutions also help to manage weather forecasting and irrigation practices such as the Adda administrative system [31] and the Aia adat water distribution system [51]. Above the community level, the State provides farmers with incentives and financial support to develop crops [37].

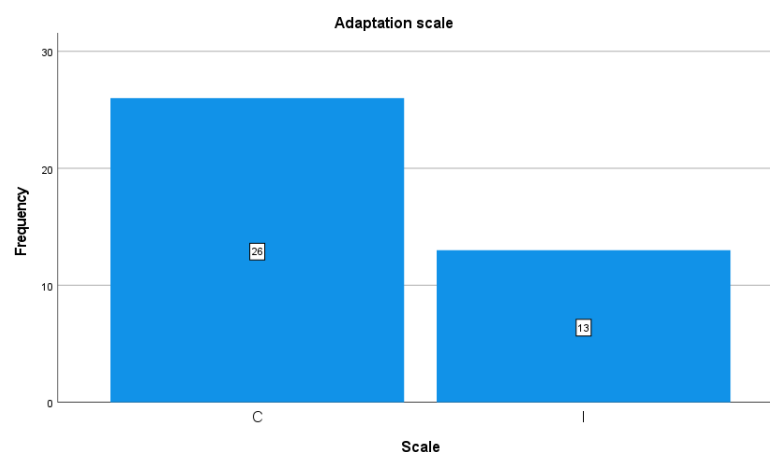
In addition, traditional institutions enforce trading rules during a crisis [53], as well as manage resources through preservation of forest area [36] and storage of resources—this includes communal food storage and distribution [53]. Division of land into ecological zones at various altitudes to be exchanged and distributed to fulfil livelihood needs across communities living in the zones [24] and banning bathing in the river during summer due to bad water quality [39] are also resource management strategies undertaken by traditional institutions. Indigenous people also manage their scarce resources by maintaining collective fishing agreements in the dry season when lakes are very shallow, avoiding deforestation and forest fires through awareness, agreements, and patrolling and increasing surveillance done by the volunteer environment agents [39].

### 3.4. *Is IKS Helping Developing World Communities Adapt to Climate Change?*

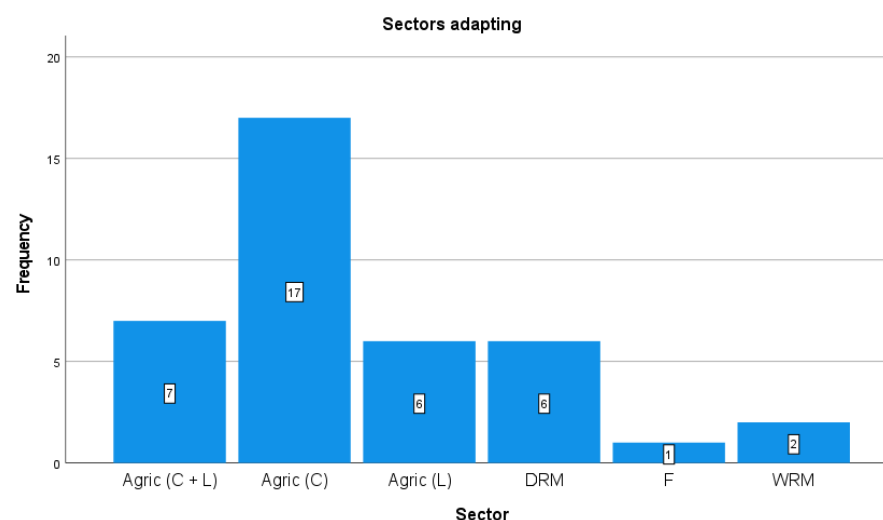
Although a few articles reported some inadequacies with IKS and its limitations in terms of helping indigenous communities adapt to climate change, for example, [48], most of the reviewed articles concluded that IKS has been helping the communities studied to adapt to climate change. Similar to Petzold et al.'s [17] findings, most of the adaptation strategies described in the reviewed studies fall under social adaptation, specifically weather forecasting and behavioural activities related to agriculture, with only a few descriptions of structural and institutional adaptation strategies. As Cordoba Vargas [37] noted, the majority of adaptation strategies consist of short-term, farm-scale agricultural practices, and thus, their impact in terms of livelihoods improvement is very limited. However, the IKS-based strategies are implemented by households and community members for themselves and are thus democratic and emancipatory. This is important for people with a history of colonialism to uphold their sense of self-actualisation and self-worth. Thus, IKS is a useful vehicle for the decolonisation of climate change education, as explored in the ensuing section.

Furthermore, individual and community-level adaptation strategies are the most widespread among the communities studied, with the latter being more prominent (Figure 9) due to the communal nature of indigenous communities. Adaptation on an individual or household scale includes activities done by individuals such as the use of local indicators, risk management, and planting activities, while adaptation on a community scale includes communal activities such as ritual practices, traditionally managed irrigation system, and community-wide rules for resource management and trading. This is unlike adaptation in the developed world where higher levels, such as municipal, regional, and national government and non-governmental organisations, international organisations, etc., are involved [55]. Similarly, adaptations are most commonly documented in the agricultural sector (Figure 10), unlike the developed world where adaptations are most commonly documented in the transportation, infrastructure, and utilities sectors [55]. This is because IKS is usually held by community members and involves a bottom-up knowledge transmission trajectory, in contrast to scientific knowledge held by academic experts who provide solutions to communities through governments and other institutions that have the

funds to engage in structural and institutional adaptation projects (top-down transmission). Lack of funds also results in the dearth of structural and institutional adaptation strategies in sectors such as ecosystem management, coastal management, energy, and public health [16]. The implication is that even though the important structural and institutional adaptation strategies needed by communities can be informed by IKS, governments and other institutions need to support the communities financially and otherwise.



**Figure 9.** Scale of IKS-based climate change adaptation. C = community; I = individual.



**Figure 10.** Sectors adapting to climate change. Sector: Agric (C + L) = Agriculture (Crops + Livestock); Agric (C) = Agriculture (Crops); Agric (L) = Agriculture (Livestock); DRM = Disaster Risk Management; F = Forestry; WRM = Water Resource Management.

Furthermore, IKS-based adaptation strategies are usually proactive rather than reactive. Although Ford et al. [16] reported that proactive strategies (mainly forecasting) were slightly higher among the African and Asian communities they studied, we found that proactive strategies (mainly forecasting and behavioural activities) were significantly higher than reactive strategies in the communities represented in the 39 articles we reviewed. This implies that the integration of IKS with scientific knowledge in climate change education will provide more proactive strategies for climate change adaptation in the developing world. Many indigenous people and communities are already combining both knowledge systems, and to a large extent, they recognise the potentials and limitations of their knowledge system. For example, rather than take their weather prediction system at face value, the Afar pastoralists, through their traditional administrative system, make a triangulation of information from different sources such as the rangeland scouts who

observe, assess, and collect information relevant to the environment and other information communication networks [31].

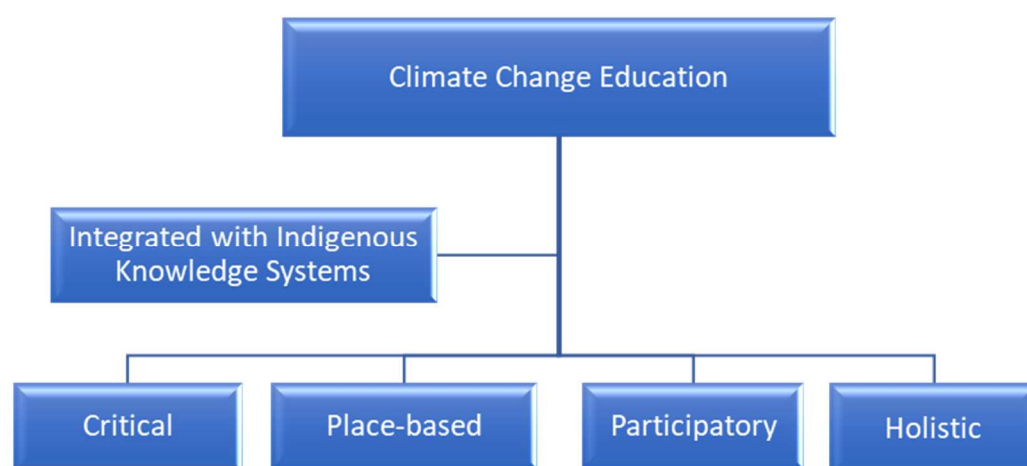
IKS's effectiveness is also limited by its rapid decline. Younger people and women were found to be hesitant to provide their indigenous knowledge, which may mean that it is not widely shared in these communities [10]. Although Walshe [24] found no evidence of the erosion of IKS in the younger demographic, majority of the reviewed articles concluded otherwise, with the highest attribution for this to its non-transmission to younger generations. The elders have to pass the knowledge on to young people orally, but the young people are usually not positioned to receive the knowledge due to various reasons such as the perceived superiority of Western or scientific knowledge [33], Christianity [11], and rural-urban migration [14]. IKS is also not very effective for many of the communities studied due to the disappearance of local flora and fauna indicators for weather forecasting [22,28]. Therefore, many indigenous communities are combining their IKS with scientific knowledge. As many of the reviewed articles concluded, neither knowledge system is sufficiently accurate and reliable, and a combination of both knowledge systems is desirable, as explicated in the ensuing section.

#### 4. Implications for Climate Change Education

Climate change education is about learning in the face of risk, uncertainty, and rapid change; it involves focus on the kind of learning, critical and creative thinking, and capacity building that will enable youth to engage with the information, inquire, understand, ask critical questions, and take what they determine are appropriate actions to respond to climate change [56]. It has been provided to indigenous people by non-indigenous (Western) people through formal education. The preceding sections show that IKS is an integral part of indigenous communities, and this needs to be reflected in their education through their involvement in the contextualisation of scientific and non-indigenous knowledge and the integration of their indigenous knowledge in existing educational systems. This is necessary because when education is from the standpoint of the people involved, it is more relatable and democratic, and therefore effective [57]. The postcolonial theory discussed earlier also explains why engaging the voices and perspectives of indigenous people is important in their own education, especially to contest epistemic violence.

In the reviewed articles, indigenous people's voices are centred, evidencing Spivak's [9] notion that the subaltern can speak and that they employ their agency to improve their lives, rather than being passive spectators. Generally, in developing world contexts where IKS and IKS-based adaptation strategies have been subjugated, the integration of IKS with existing educational systems through climate change education can begin to undo the harms of epistemic violence and restore the people's dignity. However, climate change education curricula in the developing world lack contextual relevance and devalue indigenous knowledge, in addition to Westernised assessment strategies and pedagogy methods that further reduce education effectiveness [58]. This has necessitated the integration of indigenous knowledge and practices in formal education with some success, demonstrating the importance of dialogue, power balance in decision-making processes, and mutual respect between the different parties involved [59]. These attributes were also found in a systematic review of effective climate change education strategies [60], where two general themes that were common across the effective educational interventions were identified: focusing on personally relevant and meaningful information and using active and engaging teaching methods. Four specific themes were also identified: engaging in deliberative discussions, interacting with scientists, addressing misconceptions, and implementing school or community projects.

Therefore, based on these themes for effective climate change education and based on the evidence on indigenous people's adaptation strategies described above, to be contextually relevant and respectful of IKS, an effective climate change education will be critical, place-based, participatory, and holistic, as depicted in Figure 11.



**Figure 11.** Foundations of IKS-based climate change education.

#### 4.1. Critical Climate Change Education

A critical climate change education is critical of the myth of Western superiority held by many indigenous people and imbues IKS to empower the people to reclaim their stripped dignity and humanity. For example, the statement “as indigenous practices hold high potential to address climate change, these may be promoted after establishing their scientific validity and rationality” [33] (p. 251) highlights the myth of Western superiority and the hegemony of the scientific knowledge system that climate change education ought to dispel by embracing IKS and all forms of knowledge. The validity and rationality of IKS cannot be measured by Western knowledge systems and standards, and vice versa, because both knowledge systems are rooted in the different cultures they emanate from, with differing epistemologies and values.

The use of soot to preserve seeds, selective weeding, and mixed cropping [61] are examples of some indigenous practices that have been found to be more effective than western practices for indigenous people, and these should be included in the educational content as effective adaptation strategies of indigenous people. Furthermore, climate change education should provide opportunities for questions and critical analyses, with no privileged knowledge system. The articles reviewed in this paper reveal that IKS is vast and mostly effective, and its reach and effectiveness can be significantly increased if it is embraced in climate change education and deployed at local government and national levels. This means that IKS has to be widely embraced, destigmatised, and promoted.

Essentially, indigenous knowledge-based adaptation strategies are shaped by indigenous people’s physical landscape and socio-cultural orientation towards the environment [46]. There is no ‘one size fits all’, and each community needs to engage their own IKS, even if they will adopt the practices of other communities. Through climate change education, maladaptive indigenous practices can be understood, interrogated, and discouraged. Although indigenous and other local peoples generally live in isolated communities and have little or no influence over local and national decision making on issues related to climate change [29], their voices could be included by empowering them to share their knowledge through climate change education. Deliberative discussions and addressing misconceptions about IKS and climate change are necessary.

#### 4.2. Place-Based Climate Change Education

IKS is inherently place-based, and thus, a transformed climate change education that has IKS integrated will also be place-based. In this context, to be place-based means to focus on the place (including the people, their natural environment, and sociocultural context) where the educational activities are taking place as well as “the experience of being human in connection with others and with the world of nature, and the responsibility to conserve and restore our shared environments for future generations” [62] (p. 6). There

should be more emphasis on local knowledge about weather forecasting, soil improvement, water conservation, cultural beliefs, communal pooling, etc. We know that adaptation to climate change is primarily a local process [54]; therefore, indigenous people including their local environments and knowledge systems, should be centred in climate change education. This is important because even though local communities do not only depend on IK to respond to climate change, outside knowledge is applied provided that that knowledge system conforms to their sociocultural context [26]. Thus, climate change education must be personally relevant and meaningful to the teachers and learners in the specific environments where it is being engaged. In sum, place-based pedagogy challenges educators to reflect on the relationship between the kind of education they pursue and the kind of places we inhabit and leave behind for future generations [62].

Climate change education also needs to be place-based because of the differences in the coping strategies among the different communities studied. Indigenous knowledge is particular to specific local areas and even though different indigenous people use the same or similar practices, what is more important in one community may not be for another [33]. For example, where honey production is an important economic activity in the community [49], to be place-based, climate change education in this area should include the necessary knowledge needed for sustainable honey production. This knowledge includes habitat conservation, market information, pro-environmental harvesting techniques, water resource development, efficient tree planting strategies, etc. [49]. Local knowledge, practices, and innovations are important elements for community-based coping and adaptation mechanisms, and through climate change education, they can be documented and disseminated for the present and future generations [40]. In becoming place-based, climate change education needs to consider the cultural dimensions of adaptation so that it does not automatically try to recreate, instrumentalise, or scale up indigenous adaptation strategies [24].

#### *4.3. Participatory Climate Change Education*

A participatory climate change education is essential because climate change is a continuously evolving phenomenon and thus requires continuous feedback (on current state, effective adaptation strategies, etc.) between the communities and other institutions, including educational institutions [32]. Since climate change adaptation depends very much upon local initiatives and the involvement of actors at the local level, and its effectiveness depends on how incentives for individual and collective actions are organised [39], knowledge sharing among community members, schools, and government is essential. Climate change education should be inclusive, have a power balance, and consist of knowledge that is co-generated from all stakeholders, especially community members.

Activities and educational interventions need to be engaging and inclusive, with learners implementing school or community projects [60]. In addition, emphasis should be on the importance of understanding one's environment and working as a community to overcome the challenges [51]. It is important for educational institutions to work with communities to validate and strengthen community practices, especially helping the younger members to appreciate their cultural heritage and its contributions to climate change adaptation [11]. Such hybrid knowledge co-production will enable the formation of a system that benefits both from the local relevance of indigenous techniques and the increased accuracy and efficiency of modern techniques [31]. Indigenous people are not passive victims of climate change; they have experience, knowledge, and skills to face climate challenges. Thus, it is necessary to devise methods and strengthen actions to guarantee their inclusion in environmental research, participation in the elaboration of methodologies, data collection, discussion, and appropriation of results to accomplish more inclusive and sustainable agriculture, natural resources management, and climate policies [37].

#### 4.4. Holistic Climate Change Education

A holistic climate change education is required because the severity of climate change means that all effective solutions should be employed for climate change adaptation, whether they are scientific or indigenous knowledge [10]. Neither knowledge system is perfect, and thus they need to work together and learn from each other. For example, some researchers found that the fishers in their study ‘are masters in understanding the Solunar theory [the concept of following the phases of the sun and moon], which still remains a cynical and complicated concept for many natural scientists’ [12] (p. 786). A holistic climate change education would also show IKSs’ relevance in different education disciplines across different educational levels. For example, indigenous knowledge on weather forecasting would be integrated into geography and meteorology; planting activities in agricultural science; pest and disease management in medicine and other health sciences; and structural adaptation in engineering and other technological fields. As the climate continues to change, the further promotion of the use of indigenous knowledge in agricultural production and management is not only essential but also comprises a crucial component of agency and advocacy for the rights and voices of ethnic populations globally [41]. The integration of IKS with scientific knowledge systems would be helpful by providing indigenous information in a context and format that local people are familiar with, can accept, and easily understand, but presenting it in a modern information system such as formal education curriculum or a mobile app that generates and shares information about adaptation from both indigenous and scientific knowledge systems [4].

A holistic climate change education is also necessary to help document IKS and stop harmful practices such as indiscriminate tree cutting (for firewood, building, etc.) and bird loss (for food, rituals, etc.) that are partly due to climate change but also to unsustainable practices [28]. It is important to incorporate worldview and belief systems to capture the essence of adaptation behaviour within the community. IKS is developed through a continuous process that also includes spiritual and cultural elements of knowledge holders apart from multigenerational observations and skills. These aspects are more localised and specific to certain communities based on their social, economic, and cultural needs. Hence, an adaptation plan without these elements is inoperative and leads to maladaptation to climate change [36]. Understanding indigenous adaptation methods employed by their own communities and others will provide a more holistic and relatable climate change education and options for effective adaptation strategies for people in the developing world [3].

#### 5. Conclusions

This systematic literature review of the deployment of indigenous knowledge systems towards climate change adaptation in developing world contexts found that IKS is contributing to climate change adaptation, especially in African and Asian indigenous communities. Households and communities apply IKS to forecast weather and determine agricultural practices, among other strategies. Unlike social adaptation strategies that were widely employed in the communities studied, structural and institutional adaptation strategies were minimally engaged. This is likely due to the cost-intensive nature of the latter two strategies, which are usually more engaged in the developed world. Households and communities need support from their governments and other organisations to develop their capacities to adapt structurally and institutionally. Finally, the IKS-based adaptation strategies from the reviewed articles and the reported effective strategies for climate change education in extant literature informed our recommendation of four foundations for IKS-based climate change education, with focus on adaptation.

These findings are not without limitations because most of the published studies on IKS-based climate change adaptation are from Africa and Asia, and thus the existing literature is not sufficiently representative of the developing world. In addition, the reviewed articles examined were limited to full-text peer-reviewed articles published in English language because of the impracticality of translating other languages. We also potentially

excluded some important data because, to limit the scope of the study for manageability, we only considered the timeframe of 2010 to 2020 and two databases. Nevertheless, the employed databases are two of the most encompassing, and the timeframe means we provided current evidence. Future studies should engage more languages and databases, including more publication or output types as knowledge is disseminated in different ways. For instance, the very limited outputs captured as grey literature could be extended further in future research.

However, our results reveal that through a conscientious effort, indigenous knowledge holders are applying their knowledge to reduce their vulnerability to climate change and adapt with the knowledge and resources available to them. Now more than ever, IKS is needed for self-determination and collective survival in a rapidly changing world. It is important to note that limitations of IKS have been widely documented, including certain inconsistencies in indigenous indicators [22], high spatial variability and limited availability because of dependence on oral transmission [28], and the commodification and commercialisation of indigenous healing products [63]. While the indigenous adaptation strategies derived from IKS are not perfect, their practices are characteristically sustainable and affordable as our analysis revealed, and IKSs' integration in climate change education is necessary to obtain 'the best of both worlds' in the developing world. This integration will also preserve IKS since its erosion undermines the future adaptive capacity of indigenous communities. It is also important to create space for indigenous knowledge in educational frameworks intended to support adaptation to climate change so that current and future generations and areas with high vulnerability to climate change will have more options to implement adaptive strategies that would be relevant and effective for them. In order to achieve this end, climate change education should be holistic, participatory, place-based, and critical in its conceptualisation and application.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/article/10.3390/su13094811/s1>, Table S1: An overview of the systematic review studies, Table S2: Summary data of descriptive statistics.

**Author Contributions:** Conceptualization, M.M. and S.A.; writing—review and editing, M.M., S.A., and P.M.-H.; funding acquisition, M.M. and P.M.-H. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

A clarification of search methods employed—this includes search terms, as well as inclusion and exclusion criteria.

### Search method

*Web of Science search terms:*

TS = ('indigenous knowledge' OR 'local knowledge' OR 'Traditional knowledge' OR 'Local ecological knowledge') AND TS = ('climat\* change adapt\*') OR 'Global warming adapt\*' OR 'Climat\* varia\*') AND TS = ('developing world' OR 'third world' OR 'developing countr\*')

Hit = 2790 [Date of search = 16-02-2021]

*ProQuest search terms:*

'Indigenous knowledge' (ALL)  
OR 'Local knowledge' (ALL)  
OR 'Traditional knowledge' (ALL)  
OR 'Local ecological knowledge' (ALL)  
AND 'Climate change adapt\*' (ALL)  
OR 'Global warming adapt\*' (ALL)

OR 'Climat\* varia\*' (ALL)  
 AND 'Developing world' (ALL)  
 OR 'Third world' (ALL)  
 OR 'Developing countr\*' (ALL)  
 Hit = 1360 [Date of search = 16-02-2021]

TS and ALL refer to 'Topic' and 'Anywhere except full text' respectively, and both commands result in searches across publication titles and abstracts.

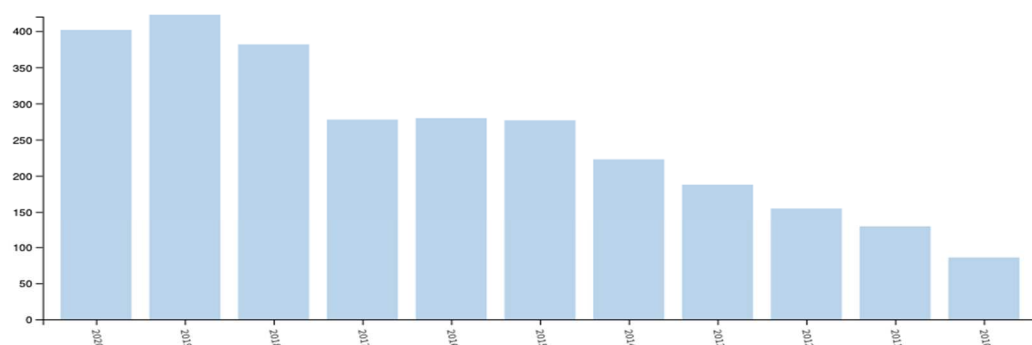


Figure A1. Distribution of number of articles retrieved from Web of Science: 2010–2020.

### Inclusion and Exclusion Criteria

Search inclusion criteria were: Year = 2010–2020. Language = English. Full text, Peer reviewed journal article. All databases. In addition, only articles that had clearly stated research questions or purposes, adaptation strategies and their climate drivers, data source and research participants were included.

During the screening of publications by title, abstract and full text, articles that were predominantly about the following were excluded from this review:

- *climate change mitigation*: developing world but focus on CC mitigation
- *climate change perception/awareness*: developing world but focus on CC perceptions
- *climate change science*: developing world but focus on CC science
- *developed world*: IKS and climate change adaptation but in the developed world
- *not IKS*: climate change adaptation in developing world but not IKS
- *not obtainable*: no title or abstract provided
- *reviews/editorials*: related articles but reviews, editorials, letters, reports, etc.
- *unrelated*: none or only one of IKS, climate change adaptation and developing world

**1. Included studies**

| Author              | Year | Title                                                                                                                                                                                                                                                                                                                                          |
|---------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Akhter, Sayma       | 2013 | Coping with Climate Change by Using Indigenous Knowledge of Ethnic Communities from in and around Lawachara National Park of Bangladesh<br>Journal of forest and environmental science<br>Added to Library: 03 Feb 2021 Last Updated: 19 Feb 2021<br>Online Link: Go to URL                                                                    |
| Balehegn, Mulubrhan | 2019 | Indigenous weather and climate forecasting knowledge among Afar pastoralists of north eastern Ethiopia: Role in adaptation to weather and climate variability<br>Pastoralism-Research Policy and Practice<br>Added to Library: 03 Feb 2021 Last Updated: 19 Feb 2021<br>View in Web of Science: Source Record, Related Records, Times Cited: 4 |
| Boko, A. N. N.      | 2016 | Local Beliefs and Strategies of Adaptation to Climate Change in Korhogo (Ivory Coast)<br>Tropicicultura<br>Added to Library: 03 Feb 2021 Last Updated: 19 Feb 2021<br>View in Web of Science: Source Record                                                                                                                                    |
| Chipungu, F. P.     | 2012 | Sweetpotato Indigenous Knowledge and Adaptation to Climate Change in Malawi<br>XVIII International Horticultural Congress on Science and Horticulture for People<br>Added to Library: 03 Feb 2021 Last Updated: 19 Feb 2021<br>View in Web of Science: Source Record, Related Records, Times Cited: 1                                          |
| Chuong Van, Huynh   | 2020 | Indigenous knowledge in relation to climate change: adaptation practices used by the Xo Dang people of central Vietnam<br>Heliyon<br>Added to Library: 03 Feb 2021 Last Updated: 20 Feb 2021<br>View in Web of Science: Source Record, Related Records, Times Cited: 0                                                                         |
| David, Wahyudi      | 2014 | Indigenous Knowledge (IK) of Water Resources Management in West Sumatra, Indonesia<br>Future of Food-Journal on Food Agriculture and Society<br>Added to Library: 03 Feb 2021 Last Updated: 20 Feb 2021<br>View in Web of Science: Source Record, Related Records, Times Cited: 5                                                              |

Figure A2. Screening in progress on EndNote Online.

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