Using Traditional Methods for Collaborative Fieldwork in a Uranium Food Chain Study on Diné Lands in the US Southwest

Christine Samuel-Nakamura

School of Nursing, University of California, Los Angeles (UCLA), 4-246 Factor Bldg., Mailcode 691821, Los Angeles, CA 90095, USA; csamnak@ucla.edu; Tel.: +1-310-206-8328

Received: 29 February 2020; Accepted: 11 June 2020; Published: 24 August 2020

Abstract: Collaborative research between scientists and local community members is often required to collect needed study samples and inform the overall study. This is particularly true in Indigenous communities where local knowledge and practices are integral to data collection, analysis, and dissemination. This study reports on a traditional ecological knowledge (TEK) collaborative methodological approach utilized for data collection in this unique community. In collaboration with Diné (Navajo) tribal harvesters and leaders in northwestern New Mexico, participants were recruited utilizing chain-referral recruitment and selection from a preexisting cohort. The research examined the extent of metal(loid) contamination in the primary food chain in a uranium (U) mining impacted area. Key food chain items (sheep, squash, herbal tea plants), water, and livestock forage samples were collected and determined for metal(loid)s (cesium, cadmium, molybdenum, lead, thorium, U, vanadium, arsenic, and selenium). This paper reports on the five-step process employed that involved local Diné food harvesters incorporating indigenous TEK and practices with Western science-based knowledge and practices. The five steps of harvest-based monitoring are: (1) identify goal and research questions, (2) design the study according to Diné and scientific protocols, (3) determine respective collaborative roles during fieldwork, (4) implement the fieldwork, and (5) analyze and disseminate the findings. Collaborative work supported constructs of respectfulness, trust, kinship, enhanced communication, and provided better understanding of contamination by researchers, community members, and leaders. The study allowed for the collection of baseline data and realistic reassessment goal recommendations for the future.

Keywords: traditional ecological knowledge; Navajo; Diné; American Indian; contamination; subsistence; harvest-based monitoring

1. Introduction

Traditional ecological knowledge (TEK), otherwise known as Indigenous knowledge or Native science, refers to the evolving knowledge acquired by Indigenous and local people over hundreds or thousands of years through direct contact with the environment [1,2]. The advantages of TEK include gathering more accurate information, being more reflective of the natural world and understanding it in a holistic manner, conducting a more ethically sound investigation, and collaboration between community members, investigators, and other stakeholders [2–6]. A more simplified definition of TEK is the “valuable knowledge about natural systems” [1] (p. 421) [2,7] that is gathered over multiple generations [8]. This knowledge is gained via experience, observation, and the analysis of natural events transmitted among community members or families [9]. In a subsistence economy, natural resources, such as traditional food, clothing, and shelter, result from such Indigenous knowledge, skills, and experience, and is further, seen to include activities such as locating, harvesting, processing,
and storing valuable cultural resources [1,10]. The direct benefits of TEK include defining and mitigating health risks, protecting natural resources related to cultural and spiritual practices, and preserving resources for future generations [11]. Finn and colleagues [12] assert that TEK is the ideal model or framework for examining and understanding environmental factors and human health [12].

Collaborative fieldwork using TEK describes harvest-based monitoring as the “long-term collection of data and samples from a subsistence harvest in order to reveal, document, and track changes in biophysical resources” [1] (p. 421). The TEK approach was well-received and has been utilized to support similar studies [8,12–16]. For example, ecology conservation field studies have used TEK or similar methods to document, characterize, and explain anthropogenic impacts to Indigenous resources [13–16], and have been utilized in the conservation of folk taxonomy, species management and protection, fish management, climate change, and environmental health studies [8,12–16].

TEK methods were ideal for collaborating with four Diné communities on the Navajo Reservation, to examine pre-existing, long-term environmental contamination. This paper details a descriptive cross-sectional study that collected baseline data for the future long-term monitoring of environmental and community changes. A five-step methodology [1], that guided the study and incorporated both traditional and science-based models is described.

Background

The Navajo Nation, located in the states of Arizona, New Mexico (NM), and Utah, has an extensive history of uranium (U) mining, dating from the 1940s to the 1980s [17], with a resultant legacy of abandoned mines and contaminated waste remaining on tribal lands. Regionally, more than 160,000 abandoned mines are located on American Indian lands in the western United States [18], with more than 500 abandoned U mines on the Navajo Nation [19]. Reservation mining districts have contributed the greatest amounts of U ore in the continental United States. Even after the procurement of an estimated 340 million pounds of natural U, approximately 300 million pounds of U reserves remain on Diné lands [20]. Mining, milling, and waste storage also remain in this area, contributing to the contamination of water, land, and locally grown foods. For instance, in 1979, the Churchrock, NM area, experienced one of the worst U spills in U.S. history, with 1100 tons of radioactive waste and 94 million gallons of acidic waste swept downstream, severely contaminating the drinking, domestic, livestock, and agricultural water used by the Diné community [21].

Uranium can affect the growth, harvesting, storage, preparation, and ingestion of traditional food items through multiple exposure pathways. In addition, multiple health risks are related to U and other associated metal(loid)s. Uranium, a radiotoxin, and cadmium (Cd), a renal chemotoxin, negatively affect the kidneys, collect in bones, are associated with hypertension, and raise the chronic health risk of renal disease and diabetes [22–24]. Lead (Pb) is associated with neurodevelopmental problems [25] and molybdenum (Mo), cesium (Cs), arsenic (As), and selenium (Se) act as teratogens, with As and Se, further, acting as reproductive toxicants [26–30]. Molybdenum and Se are essential trace elements [31] and Se has a narrow range between toxic and deficient concentrations [32]. High doses of thorium (Th), raise cancer risk [33] and vanadium (V) have been associated with adverse respiratory effects [34]. Arsenic, Cd, Pb, and Se are also associated with long-term permanent damage and sequelae.

Starting in the 1970s, health studies began identifying occupationally related chronic illnesses in local mine workers. As such, lung cancer was found to be associated with the radioactive decay chain of U radon daughters [35,36]. Health concerns regarding the general lack of data regarding the environmental distribution of U in relation to chronic kidney disease and community and leadership concerns propelled local environmental studies [17,21]. As a result of the negative impacts of U mining to health, culture, and natural resources, a Diné tribal moratorium was placed on U mining in April 2005, to prevent the future development of mining and similar anthropogenic activities [17,37].

Among Indigenous groups such as the Diné, food and herbs are central in medicinal and healing ceremonies, weddings, naming and coming of age ceremonies and other important community gatherings. The harvesting of sustainable local foods is richly steeped in history and is embedded
in cultural rituals, healing, and ways of life [38] and supports its cultural value and relevance. Diné members hold culture-bound food planting, harvesting, and animal husbandry practices that have continued for generations. Locating, growing, and harvesting food strengthen connectedness and respectfulness between food and the land, fortify community interactions and k’é (Diné word for kinship), provide “coming-to-know” or learning opportunities, and reinforce constant participation in food and resource use and sustainability [39] (p. 80). Seasonal planting and associated activities are collaborative efforts among local community members. An associated activity, locating safe water, is a challenge, because water is scarce in this area, resulting in “dry farming” being the typical agricultural method used in this region. However, due to a current longstanding drought, fewer community members participate in farming activities [40,41].

In addition to plant sustenance, sheep are also valued for their many resources. Sheep are culturally valuable animals, highly prized for their protein, wool, and parts used in various healing ceremonies. Other benefits include providing a reliable income, “cash on the hoof”, during emergencies and being a reliable food source in times of famine [42] (p. 24). They are also seen as a means of educating children in the Diné way of life, meeting the tribal government requirements for traditional land-use rights, and providing for the cultural and spiritual needs of the community [40]. A well-kept herd adds to ones’ potential or perceived worthiness for leadership, social identity, and responsibility, and is a major component of ones’ general wellbeing [43]. The Diné have continuously herded sheep since at least A.D. 1700. In the past, their herding methods mirrored those of nomadic people, who moved with their herds across great distances [42]. This method of herding has continued on a smaller scale over the years and is still seen as part of the Diné way of life. The common Diné adage is “díbé inániliní át’é” or “sheep is life” [43] (p. 1442). Today, it remains a significant part of the daily lives of the community as a primary protein source, and serves as a vital cultural resource and occupation to dye and weave textiles (clothing and rugs) and other implements.

Given this background, a University of California Los Angeles researcher entered into a collaborative research study that incorporated indigenous TEK and practices with Western science-based knowledge and practices. Study participants were selected based on DiNEH data [21], that identified them as participating in local planting and harvesting activities and by the use of snowball methods (word-of-mouth or referral). First defined and exhibited by Huntington [2], the TEK formed the foundation of this process and became the guiding principle through the duration of the study. This study reports on the collaborative study methodology that was utilized; specific metal(loid) data are reported elsewhere [44–46].

2. Materials and Methods

Tribal approvals are required from “Chapters” (local self-governing community political units) held at meeting halls, or “Chapter Houses,” as well as other associated agencies, such as the Navajo Department of Health, Eastern Navajo Health Board, Eastern Navajo Agency Council, and the tribal research Institutional Review Board (IRB). Four tribal sites or self-governing Chapters were approached by the University of California, Los Angeles (UCLA) researcher seeking collaboration on a study to examine U and associated metal(loid) contamination in their communities (Figure 1). Meetings with tribal communities, leaders, and other researchers formulated the research question and focused on local key foods, harvesters, and processes. Key food harvesters were identified from a previous study cohort [21] and approached to enroll in the current study. In addition, those identified by the snowball method were also included in the enrollment. A five-step process [1] guided local harvest-based monitoring; (1) identify goals and research questions, (2) design the study steps according to Diné and scientific protocols, (3) determine respective collaborative fieldwork, (4) implement the fieldwork, and (5) analyze and collaboratively agree to disseminate the findings.
A main requirement for participatory research is identifying the goals of the study, that in turn, formulate the research questions [11,17,47]. Without a common goal for the research, the process cannot be supported by the tribal communities and leadership. The research goals and questions of this study were derived from an earlier report, identifying contaminated food as a primary concern of Diné tribal members [21] in the current study area. This study focused on determining the extent of food contamination by U and other associated metalloid(s). In particular, sheep, crops, and herbs were identified as important and valuable food and cultural resources. Environmental samples of water, soil, and livestock forage were also included. Other community concerns were related to the direct impact of contamination on the abundance and accessibility of harvested food items and their contribution to a longstanding traditional livelihood, particularly tea and medicinal herbs. Multiple significant health and socioeconomic factors were considered in developing the joint research goals and questions. For instance, the Diné are significantly impacted by food insecurity issues, socioeconomic factors, obesity, early onset chronic kidney disease, and elevated risk factors for kidney disease, such as diabetes and hypertension [21,48]. The opportunity to address these factors informed community interest in participating in this study.

3. Step 2: Designing the Study Components

The study design contained all required components of a relevant scientific inquiry, such as identifying the study sites, determining the research approach and variables of interest, data collection, appropriate analytic methods [44–46], and the dissemination of findings. In order to incorporate Indigenous TEK and practices with Western science-based practices, the research protocol included established Diné cultural harvesting practices [38], inquirer experience and observations related to seasonal food collection, animal tissue and plant collection methods, and storage of collected samples. Further, practical experimental knowledge for the ideal selection of the plant samples to promote new growth, the careful extraction of plant samples to limit damage to aboveground and root parts, and proper handling of meat, pelt, and wool were illustrated by study participants. Important components included in the design of the study included incorporating cultural knowledge and providing provisions for multiple approval stages at the individual, community, and tribal levels.

The study design for sheep harvesting was developed to benefit the researcher and harvester in several ways. Cultural knowledge of the recommended order of sheep butchering for sample collection was incorporated. Research procedures were designed to reduce time, unnecessary effort, minimize field and/or food contamination, and minimize the disruption to family harvesting and essential work activities. To ensure that the timing of the sheep harvesting was practical and within tribal practices,
Another TEK requirement adopted into the study protocol was the provision for tribal approvals. First, each tribal community was approached to consent to participate in the study. Next, the individual tribal harvesters provided their consent to participate in the study. Lastly, the Navajo Nation Human Research Review Board (NNHRRB) provided the final review and approval of the research protocol. Any necessary changes to the protocol were completed before the study was allowed to proceed. In the latter phases of the study, the publishing of the study findings were reviewed and approved by the NNHRRB. Understanding the culture and the local language were important parts of the approval process. As Diné is the spoken primary language on the Navajo reservation, the proposal to conduct the study contained sufficient lay terms for the ease of understanding scientific concepts and terms by the leadership, community, and harvesters. The Diné language is historically an oral language, and is not commonly read or written by the community [21]. For this reason, study information was disseminated in an oral versus written format to community members. The study timeframe, community benefits, sites for data collection, participant involvement and reporting, publication process and approvals were clearly delineated in both languages (Diné and English). Following IRB approval from UCLA, review and approval were obtained from the Navajo Nation Human Research Review Board (NNHRRB). The study was then implemented and has been ongoing since 2011. Following data analysis, report development, and on-site reporting at the collaborating sites, special oral reports provided to the NNHRRB included mandatory participation in research conference meetings. The final study findings were reported in both Diné and English languages and ample opportunities were provided for discussion and questions at each participating Chapter site. The design of the study was informed by local TEK and science-based protocols, provided provisions for tribal approvals, and provided study information and discussion in a format that was equitable for researchers, community members, and the tribe.

3.3. Step 3: Determine Roles for Fieldwork

Fieldwork roles were developed to maximize the skills and knowledge of all study collaborators. The researcher maintained the protocol timeframe and oversaw all data collection, analysis, and reporting of findings. This included the maintenance of document security, storage, and transportation of material and data. In addition, acquiring the informed consent and IRB approvals and completing progress reports also fell within the responsibilities of the researcher. Several roles emerged and were dependent on the type of harvesting activity (plant, animal, or crop). The most important harvester role functions included providing geographical navigation, providing detailed information on harvested food items (i.e., animal health, grazing pattern, foraging details, tea or squash consumption), water and food ingestion or exposure information and areas known to be contaminated or areas of concern.

Tribal harvesters held important information on Indigenous planting practices, ideal harvesting sites, and Indigenous protocols for collecting samples from plants and animals, as well as land management practices. Harvesters worked in conjunction with the researcher to recommend sites for sample collection from sheep, squash, tea plants, and associated environmental samples (water, soil, and forage). For sheep grazing sites, shepherds would join the researcher to report grazing sites using printed maps with paths or roads identified for travel. The researcher developed processes for selection, extraction, and handling of the samples to obtain ideal specimens and avoid cross-contamination. Harvesters identified tea collection areas, demonstrated tea collection techniques by hand, detailed its preparation and reported on the frequency and amount of consumption, thus providing new knowledge for the researcher that enabled an adequate description of food harvesters’ intakes, evaluate risk, and consider future impacts.
Identifying harvest locations encompassed assessing and mapping many acres of often inaccessible land and covering great distances in rustic environs. Sheep grazing areas tended to contain the greatest range and landmass. Thus, local Diné shepherds were relied upon to report grazing areas and patterns, common watering sites, as well as the primary species of plants foraged upon by the herd. The researcher provided printed topographic maps while harvesters pinpointed sites and provided descriptions of landmarks, conditions, and types and distribution of the species of plants expected to be found. They also identified the best path or route to these sites if taken by foot or truck. The names of plants in the Diné language, general plant descriptions, and common indications for animal and human use were noted and were referred to in subsequent community discussions and reports. Each assessed sample and area of use was marked with a global positioning system instrument, analyzed, and mapped. Frequent references were made to these materials throughout the duration of the study, for community and leadership interactions.

Obtaining samples from local sheep to assess contamination required information on their care, grazing locations, and history of health problems or symptoms of possible overexposure to metal(loid)s. Contaminants may be present in water, grazing, and feed areas; accordingly, individual sheep and herd history of land-pattern use near known areas of mining or toxic waste were essential. Without harvester knowledge of these sites, it would have been challenging to locate common areas of grazing and their proximity to mining sites and structures, properly identify and quantify the species of forage plants consumed by sheep, and identify and sample water sources. Collecting samples from a meat market, interacting with non-shepherd owners, or other second-hand persons would bear far less reliable information on the grazing locations in relation to exposure sites, patterns, forage and water consumption, and the health information of individual sheep and the herd.

Harvesters were also relied upon to locate and describe local water use. Previous work revealed that community members haul or transport water great distances for their livestock and for shared drinking and domestic use [17]. Community water sources varied greatly in terms of regulation status as well as their metal(loid) concentrations [17,44–46]. Notably, unregulated water is not tested or treated to minimize contaminant concentrations and is not required to meet primary drinking water standards set by the United States Environmental Protection Agency, the states or tribes, in relation to the Safe Drinking Water Act [19]. Unregulated water sources include those intended for livestock use, earthen dam water, ephemeral sources, private wells, and rainwater capture. Harvesters informed the researcher as to whether regulated or unregulated water was utilized to water sheep or crops, the locations of water sources, and information related to the amount and frequency of use. The researcher used this information to accurately target and collect water samples, examine harvester water collection behavior, and evaluate risk to foods by way of water exposure and use. Upon discussion with community members and leaders, the risk of using repurposed metal vessels from a high-risk area was determined to be unsafe and safer alternatives were identified and reinforced. Safer alternatives include those water sources identified by the Navajo Nation Environmental Protection Agency (NNEPA), deLemos et al. [21], and those from regulated or public water systems. The roles and expectations were determined by all stakeholders and provided the means to implement and enhance the fieldwork and allowed for the exchange of valuable exposure information.

3.4. Step 4: Implement Fieldwork

The fourth stage includes data collection and the fieldwork component of the study. Rural fieldwork can have many unexpected events (i.e., inclement weather, sample courier schedule delays, sampling tool or instrument problems) and developing back-up or contingency plans was essential (e.g., having serial optional sampling dates available, have samples ready earlier in the week outside of weekends or holidays, extra sampling equipment and familiarity with troubleshooting techniques). Two key examples of the implementation of fieldwork will be described for wild tea and protein harvesting. Diné tea plants (*T. megapotamicum* [Spreng.] Kuntze) are perennial plants and have a wide distribution on the reservation. The selection and harvesting of suitable tea plants is important to support
the protection and conservation of harvestable plant species. Harvesters exclusively pinch-off the aboveground portion of the plant by hand near the root, to allow regeneration and support the availability of the plant for future generations. The best-looking and tallest plants were not selected or pulled at the root, again, to ensure future community availability. For the purposes of the study, the roots of the tea plants were obtained to determine metal(loid) concentrations. So as not to disrupt conservation efforts and breach cultural requirements, the most robust plants and areas with lesser distributions were not sampled. Harvesters informed the researchers that they were taught by knowledgeable herb harvesters to pick from ideal areas with low human and animal traffic. However, a few participants reported picking tea from both busy and non-busy roadways. In addition, the investigators found that one-third of tea harvesters did not rinse the tea leaves before steeping them for consumption. This then raised the possibility that metal(loid) tea concentrations could be higher in non-rinsed tea leaves or those collected near busier vehicle roadways [44].

The researcher was encouraged to be conservative in the selection, sampling, and preservation of sheep tissue. Harvesters did not want to waste food, nor compromise the quality of cultural implements such as animal pelts and wool. The harvesters recommended that a conservative number of animals and sample sizes be selected for research (incidentally also a protocol requirement of the UCLA animal research tissue-sharing program). For example, sample sizes and weights were predetermined and established before actual field collection to minimize food waste and time. The necessary sample numbers and sizes for each food item were reported at all recruitment community meetings. Harvesters also instructed the researcher to avoid grabbing the animal, to reduce the chance of bruising the meat or damaging the pelt or wool. Diné procedures for handling the animals were demonstrated and explained by harvesters with assistance from elder or expert family members. Finally, the recommended practice of showing gratitude and respectfulness to the animal for providing food and other valuable cultural resources was practiced, as it is a common and documented practice in North American Indian communities [15,39,43]. Such communities also practice thankfulness for the healing properties of plants and animals, especially in conjunction with blessings, prayers and ceremonies [49].

Due to the exchange of information, researchers were able to obtain samples that bore valuable exposure information, and, in some instances, harvesters observed and/or participated in collecting samples. The process for each method was demonstrated and discussed, thus providing valuable exposure information and baseline descriptive data about harvesters and their dietary intake and behaviors. These exchanges also provide opportunities for harvesters to observe and participate in scientific methods and processes.

3.5. Step 5: Analyze and Disseminate Study Findings

Analyzing and disseminating study findings is an important step in the research trajectory. Analysis of preliminary results and final reports were provided to the community and leadership in various formats for discussion and information sharing. In the Native science perspective, analysis is seen as a non-linear process, whereby observation, analysis, and the outcome are known to be complex and interconnected [39]. Harvesters voiced concerns over these intricate interrelationships. For example, there was greater focus on the overall impact of food web contamination, rather than on single food chain items. Further, there was an overall concern of the impact to future generations, in terms of abundance, accessibility, and impact to livelihood. The harvesters interpreted field results in collaboration with the researcher throughout the study process. In a role reversal, harvesters postulated that tea plants harvested near busier roadways would likely contain greater metal(loid) concentrations than those near less busy roadways, due to vehicle combustion and dust, a conclusion later supported by final results [44]. Similar results supporting dust deposition as a major contributor on foodstuffs were demonstrated, with metal(loid) concentrations found in sheep wool (As, Pb, and U) [45] and squash (Cd, Mo, Se, and Th) [46]. The preliminary and final analysis and findings were reported and discussed at community and leadership meetings. Further findings were included in periodic and annual reports to the tribe and funding agencies, and community and research conferences.
Findings may be instrumental in mitigating risk, may lead to significant policy changes, and serve as an instrument for education and monitoring of the community. Study findings (and included periodic reporting requirements, annual review, invited lectures, and biennial tribal conference reporting) were presented simultaneously to the NNHRRB, harvesters and local communities. The Navajo Nation is a sovereign nation, whereby they are able to govern themselves, implement policies, and enforce them. Upon study protocol closure, the data will be provided to the Navajo Nation Data Resource Center repository for storage and future use, per the Navajo Nation research policy. The study findings were also presented in several formal presentations to the NNHRRB, each participating tribal community, participating leadership agencies, tribal healthcare facilities, and tribal and non-tribal conferences [44–46].

The study findings highlight the importance of further research and monitoring of locally raised and harvested traditional foods (particularly regarding Se found in meat protein and Cd and Mo in tea). At the local level, the findings emphasize the use of regulated water, rather than unregulated sources; encourage the use of water and soil usage maps suggested by deLemos [21]; recommend utilizing metal(loid)-free water vessels as advised by the NNEPA [50] for agricultural purposes; urge caution in consuming tea harvested from high vehicle traffic areas; and support informed choices regarding local food harvesting, preparation, consumption, sharing, storage and sale. Publications served to inform the scientific, healthcare, and lay communities on findings that may guide other research endeavors and monitoring projects, and educate researchers about environmental health research methodologies, based on partnerships with cultural adeptness, respectfulness, and competence.

4. Discussion

Incorporating Indigenous TEK and practices with Western science-based practices can be a time-consuming and challenging undertaking; however, the outcomes are well worth the effort. Similar studies have found the use of TEK to be feasible and beneficial in combination with Western scientific methods [1,12,15,16,51]. It was important that there was a clear understanding of the research protocols, sample selection and collection, and that individual roles were developed. The researcher was dependent on the local harvesters to select the animals and associated samples, as the harvesters were aware of the grazing locations and patterns of the sheep herds, as well as the procedures and a timeline for protein harvesting. Thus, the harvesters determined the time, site, and collection of the samples for analysis. Opportunities for the researcher and harvesters to learn from each other proved to be an important aspect of the study. Whereas the Diné learned Western research methods and practices, the researcher acquired knowledge of culture-bound practices, beliefs, language considerations, and harvesting behaviors. For instance, from direct harvester information, the researcher learnt the incidence and frequency of food sharing and selling by tribal members to supplement their income. Studies have shown that community knowledge surrounding food sharing and the community pooling of resources were common to meet the many food shortage challenges encountered over multiple generations [51,52]. The importance and frequency of the use of cultural implements and the various uses of local food in ceremonies were illustrated and contributed to baseline data. Adhering to seasonal planting practices, avoiding food damage and waste were reinforced in the TEK process. This, in turn, provided the best practices for sampling plant and animal tissue, maximizing sample integrity, and reducing damage and waste. In addition, knowledgeable tribal members emphasized the need for respectfulness and thankfulness during the entire harvesting process (from locating food to the consumption and storage of harvested foods). This respectfulness, socio-ecological resilience, and protection of resources were a common theme exhibited in similar studies [1,15,16,51–53]. Thus, cultural relevance and humility were demonstrated and promoted during harvesting activities, by both research partners. Multiple studies emphasize the importance of cultural humility for successful collaboration with American Indian/Indigenous community research projects [12,17,54].

A researcher with previous experience working in American Indian communities was a valuable source of knowledge about lifestyles, project sites, and research methods. A strong background in
culture, language, agriculture, animal husbandry, and environmental health sciences was essential for the implementation of the study. In addition, the principal investigator, a member of the Diné Nation, spoke the language fluently, contributing to good communication, promoted an improved understanding of the research process, and enhanced trust and k’élé.

The researcher was tasked with educating local harvesters and tribal leaders on Western methods of approaching science, measurements, assessment, and monitoring metal(loid) contamination in the primary food chain. This information was carefully translated and illustrated in local, tribal leadership, and agency discussions. Presentations on the collaborative method and study findings were provided at the biennial NNHRRB research conferences, in posters, and in peer-reviewed publications [44–46]. In addition, the participation in community meetings and events further strengthened the knowledge, inclusion, and trust of the community, which are described as being essential in similar tribal environmental health studies [12,17]. This five-stage collaborative approach, fostered trust and strengthened community kinships and relationships. Benefits to the community included co-learning, developing and strengthening relationships with researchers to enhance community acceptance and providing research protections, and is a model for other American Indian/Indigenous communities. The inclusion of the community and leadership throughout the study provided an enhanced understanding of the strengths and limitations of the study and the important factors related to contamination in the food chain, and provided realistic recommendations for future research.

5. Conclusions

Incorporating Indigenous TEK practices with Western, science-based practices was an important addition to the environmental research conducted in this study. Adhering to the five-step methodology proved acceptable and valuable for cross-cultural communication, understanding roles, determining sample collection methods, and setting expectations for the outcome. This research was both feasible and acceptable to the tribal community, who learned Western scientific methods and measures as a result of the study. For the university researcher, incorporating TEK helped to identify and gather key traditional foods and environmental information and samples. The researcher learnt the importance of American Indian methods of protecting and preserving harvesting areas, seasonal collection schedule, harvesting locations and methods, and collection approaches to reduce waste and harm. Thus, the scientific approach used by this study served as a framework to educate and strengthen both sides of this partnership.

The strategy used in this collaborative work supported the constructs of respectfulness, trust, kinship, and enhanced communication, while providing a better understanding of contamination to the researcher, community members, and leaders. Furthermore, the work collected baseline data that support realistic reassessment goals and recommendations for the future. For example, long-term metal(loid) monitoring is recommended and expanding upon key areas that bear further study, which include sheep protein, herbal tea, crops (and other locally grown and harvested foods), livestock forage, water sources, and associated environmental samples. Important beliefs and behaviors emerged that impact metal(loid) exposure, including the commonality of food selling and sharing, and high-risk behaviors, such as not rinsing tea before consumption, and using unsafe, repurposed materials for water ingestion, transport, and storage. Notably, the possible environmental impacts of U and the co-occurrence of multiple contaminants were detected and reemphasized to community members, researchers, and the tribal leadership. Further examination and research are needed in this area, including long-term monitoring and surveillance, which should continue to employ this collaborative model to further benefit from the inclusion of important cultural knowledge that enhances the research process and provides future avenues of research.

Funding: This research was funded by the National Institute of Nursing Research (NINR) of the National Institutes of Health (NIH), under Award Number F31NR013102. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. This work was also supported by the NIH/NINR T32NR007077; the University of California, Los Angeles (UCLA), National Institute
for Occupational Safety and Health (NIOSH) 2 T42 OH 8412-8, the 2012-13 UCLA Institute of American Cultures (IAC), and the 2011–2013 Navajo Nation.

Acknowledgments: I would like to acknowledge the four participating Diné communities in New Mexico and the Navajo Nation Human Research Review Board (N HHRRB). The assistance of Johnnye Lewis of the University of New Mexico (UNM) Community Environmental Health Program (CEHP), College of Pharmacy, Bob Sivinski of the UNM Herbarium, Chris Shuey and Sandy Ramone of the Southwest Research Information Center (SRIC), and Mehdi Ali and staff at the UNM Analytical Chemistry Laboratory Earth and Planetary Sciences Department are deeply appreciated.

Conflicts of Interest: The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Bell, R.; Harwood, L. Harvest-based monitoring in the Inuvialuit Settlement Region: Steps for success. *Arctic* 2012, 65, 421–432. [CrossRef]
2. Huntington, H. Using Traditional Ecological Knowledge in science: Methods and applications. *Ecol. Appl.* 2000, 10, 1270–1274. [CrossRef]
3. Agrawal, A. Dismantling the divide between Indigenous and scientific knowledge. *Dev. Chang.* 1995, 26, 413–439. [CrossRef]
4. Colorado, P. Indigenous Science. *ReVision* 1996, 18, 6–10.
5. Deloria, V. If you think about it, you will see that it is true. *ReVision* 1996, 18, 37–44.
6. Hansen, B.V. Proceedings of the AEPS and Indigenous Peoples Knowledge: Report on Seminar on Integration of Indigenous Peoples Knowledge, Reykjavik, Iceland, 20–23 September 1994; Ministry for the Environment: Reykjavik, Iceland; Ministry of the Environment and Home Rule of Greenland: Copenhagen, Denmark, 1994.
7. Dowler, D. The use of traditional knowledge by the Fisheries Joint Management Committee in the Inuvialuit Settlement Region. In *A Seminar on Two Ways of Knowing: Indigenous and Scientific Knowledge*; Fehr, A., Hurst, W., Eds.; Aurora Research Institute: Inuvik, NT, Canada, 1996; pp. 62–63.
8. Drew, J.A. Use of Traditional Ecological Knowledge in marine conservation. *Conserv. Biol.* 2005, 19, 1286–1293. [CrossRef]
9. Huntington, H.P. Observations on the utility of the semi-directive interview for documenting Traditional Ecological Knowledge. *Arctic* 1998, 51, 237–242. Available online: www.jstor.org/stable/40512135 (accessed on 15 May 2019). [CrossRef]
10. Usher, P. Traditional Ecological Knowledge in environmental assessment and management. *Arctic* 2000, 53. [CrossRef]
11. McOliver, C.A.; Camper, A.K.; Doyle, J.T.; Eggers, M.J.; Ford, T.E.; Lila, M.A.; Berner, J.; Campbell, L.; Donatuto, J. Community-based research as a mechanism to reduce environmental health disparities in American Indian and Alaska Native communities. *Int. J. Environ. Res. Public Health* 2015, 12, 4076–4100. [CrossRef]
12. Finn, S.; Herne, M.; Castille, D. The value of Traditional Ecological Knowledge for the environmental health sciences and biomedical research. *Environ. Health Perspect* 2017, 125, 085006. [CrossRef]
13. Frohmberg, E.; Goble, R.; Sanchez, V.; Quigley, D. The assessment of radiation exposures in Native American communities from nuclear weapons testing in Nevada. *Risk Anal.* 2000, 20, 101–111. [CrossRef] [PubMed]
14. Thomas, P.A.; Gates, T.E. Radionuclides in the lichen-caribou-human food chain near uranium mining operations in northern Saskatchewan, Canada. *Environ. Health Perspect* 1999, 107, 527–537. [CrossRef] [PubMed]
15. Tsuji, L.J.; Manson, H.; Wainman, B.C.; Vanspronsen, E.P.; Shecapio-Blacksmit, J.; Rabbitskin, T. Identifying potential receptors and routes of contaminant exposure in the traditional territory of the Ouje-Bougoumou Cree: Land use and a geographical information system. *Environ. Monit. Assess.* 2007, 127, 293–306. [CrossRef] [PubMed]
16. Tsuji, L.J.S.; Cooper, K.; Manson, H. Utilization of land use data to identify issues of concern related to contamination at site 050 of the mid-Canada radar line. *Can. J. Nativ. Stud.* 2005, XXV, 491–527.
17. deLemos, J.; Rock, T.; Brugge, D.; Slagowski, N.; Manning, T.; Lewis, J. Lessons from the Navajo: Assistance with environmental data collection ensures cultural humility and data relevance. *Prog. Community Health Partnersh.* 2007, 1, 321–326. [CrossRef]

18. Lewis, J.; Hoover, J.; MacKenzie, D. Mining and environmental health disparities in Native American communities. *Curr. Environ. Health Rep.* 2017, 4, 130–141. [CrossRef]

19. Erdei, E.; Shuey, C.; Pacheco, B.; Cajero, M.; Lewis, J.; Rubin, R.L. Elevated autoimmunity in residents living near abandoned uranium mine sites on the Navajo Nation. *J. Autoimmun.* 2019, 99, 15–23. [CrossRef]

20. McLemore, V.T.; Hill, B.; Khalsa, N.; Lucas Kamat, S.A. Uranium resources in the Grants uranium district, New Mexico: An update. New Mexico Geological Society Guidebook. [64th Field Conference, Geology of Route 66 Region: Flagstaff to Grants. 2013. Available online: https://nmggs.nmt.edu/publications/guidebooks/downloads/64/64_p0117_p0126.pdf (accessed on 14 May 2017).

21. deLemos, J.L.; Brugge, D.; Cajero, M.; Downs, M.; Durant, J.L.; George, C.M.; Henio-Adeky, S.; Nez, T.; Manning, T.; Rock, T.; et al. Development of risk maps to minimize uranium exposures in the Navajo Churchrock mining district. *Environ. Health 2009*, 8, 29. [CrossRef]

22. Hund, L.; Bedrick, E.J.; Miller, C.; Huerta, G.; Nez, T.; Ramone, S.; Shuey, C.; Cajero, M.; Lewis, J. A Bayesian framework for estimating disease risk due to exposure to uranium mine and mill waste on the Navajo Nation. *J. R. Stat. Soc. Ser. A* 2015, 178, 1069–1091. [CrossRef]

23. Kurttio, P.; Komulainen, H.; Leino, A.; Salonen, L.; Auvinen, A.; Saha, H. Bone as a possible target of chemical toxicity of natural uranium in drinking water. *Environ. Health Perspect 2004*, 113, 68–72. [CrossRef]

24. Taylor, D.M.; Taylor, S.K. Environmental uranium and human health. *Rev. Environ. Health 1997*, 12, 147–157. [CrossRef] [PubMed]

25. Caldás, E.D.; Machado, L.L. Cadmium, mercury and lead in medicinal herbs in Brazil. *Food Chem. Toxicol.* 2004, 42, 599–603. [CrossRef] [PubMed]

26. Eisler, R. *Arsenic Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review; Report 12; Biological Report 85(1.12). Contaminant Hazard Reviews, Issue. F; U.S. Department of the Interior, Fish and Wildlife Service: Laurel, MD, USA, 1988. Available online: http://pubs.er.usgs.gov/publication/p200037 (accessed on 1 July 2019).

27. Grignard, E.; Gueguen, Y.; Grison, S.; Lobaccaro, J.M.; Gourmelon, P.; Souidi, M. In vivo effects of chronic contamination with 137 cesium on testicular and adrenal steroidogenesis. *Arch Toxicol.* 2008, 82, 583–589. [CrossRef] [PubMed]

28. Meeker, J.D.; Rossano, M.G.; Protas, B.; Diamond, M.P.; Puscheck, E.; Daly, D.; Paneth, N.; Wirth, J.J. Cadmium, lead, and other metals in relation to semen quality: Human evidence for molybdenum as a male reproductive toxicant. *Environ. Health Perspect 2008*, 116, 1473–1479. [CrossRef] [PubMed]

29. Meeker, J.D.; Rossano, M.G.; Protas, B.; Padmanabhan, V.; Diamond, M.P.; Puscheck, E.; Daly, D.; Paneth, N.; Wirth, J.J. Environmental exposure to metals and male reproductive hormones: Circulating testosterone is inversely associated with blood molybdenum. *Fertil. Steril.* 2010, 93, 130–140. [CrossRef] [PubMed]

30. Vinceti, M.; Cann, C.I.; Calzolari, E.; Vivoli, R.; Garavelli, L.; Bergomi, M. Reproductive outcomes in a population exposed long-term to inorganic selenium via drinking water. *Sci. Total Environ.* 2000, 250, 1–7. [CrossRef]

31. Schwartz, G. Molybdenum in human health and disease. In *Interrelations between Essential Metal Ions and Human Disease; Metal Ions in Live Sciences; Sigel, A., Sigel, H., Sigel, R., Eds.; Springer: Dordrecht, The Netherlands, 2013; Volume 13.

32. Tan, J.; Zhu, W.; Wang, W.; Li, R.; Hou, S.; Wang, D.; Yang, L. Selenium in soil and endemic disease in China. *Sci. Total Environ.* 2002, 284, 227–235. [CrossRef]

33. Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile for Thorium; ASTDR in collaboration with the U.S. Environmental Protection Agency: Washington, DC, USA, 1990. Available online: https://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=660&tid=121#bookmark15 (accessed on 15 October 2010).

34. ATSDR. *Toxicological Profile for Vanadium; U.S. Department of health and Human Services: Washington, DC, USA, 2012. Available online: https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=276&tid=50 (accessed on 15 October 2010).

35. Lundin, F.E.; Wagoner, J.K.; Archer, V.E. *Radon Daughter Exposure and Respiratory Cancer Quantitative and Temporal Aspects* (00092887); NIOSH-NIEHS Joint Monograph No. 1: Cincinnati, OH, USA, 1971. Available online: https://www.cdc.gov/niosh/nioshtic-2/00092887.html (accessed on 1 October 2019).
36. Samet, J.M.; Kutvirt, D.M.; Waxweiler, R.J.; Key, C.R. Uranium mining and lung cancer in Navajo men. *N. Engl. J. Med.* 1984, 310, 1481–1484. [CrossRef]

37. Navajo Nation Council. Diné Natural Resources Protection act of 2005. CAP-18-05. 2005. Available online: https://www.scribd.com/doc/129330956/2005-Dine-Natural-Resources-Protection-Act-of-2005-Amending-Title-18-of-the-Navajo-Nation-Code-Banning-Uranium-Mining-Milling-on-the-Navajo- (accessed on 15 July 2019).

38. Hill, W.W. *The Agriculture and Hunting Methods of the Navaho Indians*; Yale University Press: New Haven, CT, USA, 1938.

39. Cajete, G. *Native Science: Natural Laws of Interdependence*; Clear Light Publishers: Sante Fe, NM, USA, 2000.

40. Setala, A.; Bleich, S.N.; Speakman, K.; Oski, J.; Martin, T.; Moore, R.; Tohannie, M.; Gittelsohn, J. The potential of local farming on the Navajo Nation to improve fruit and vegetable intake: Barriers and opportunities. *Ecol. Food Nutr.* 2011, 50, 393–409. [CrossRef]

41. Setala, A.; Gittelsohn, J.; Speakman, K.; Oski, J.; Martin, T.; Moore, R.; Tohannie, M.; Bleich, S.N. Linking farmers to community stores to increase consumption of local produce: A case study of the Navajo Nation. *Public Health Nutr.* 2011, 14, 1658–1662. [CrossRef]

42. Kuznar, L.A. Ecological mutualism in Navajo corrals: Implications for Navajo environmental perceptions and human/plant coevolution. *J. Anthropol. Res.* 2001, 57, 17–39. Available online: www.jstor.org/stable/3630796 (accessed on 12 December 2019). [CrossRef]

43. Witherspoon, G. Sheep in Navajo culture and social organization. *Am. Anthropol.* 1973, 75, 1441–1447. Available online: www.jstor.org/stable/674041 (accessed on 12 December 2019). [CrossRef]

44. Samuel-Nakamura, C.; Hodge, F.S.; Valentine, J.; Robbins, W.A. Heavy metal contamination in *Thelesperma megapotamicum*. *J. Toxicol. Environ. Health Sci.* 2017, 9, 4–22. [CrossRef]

45. Samuel-Nakamura, C.; Robbins, W.A.; Hodge, F.S. Uranium and associated heavy metals in *Ovis aries* in a mining impacted area in Northwestern New Mexico. *Int. J. Environ. Res. Public Health* 2017, 14, 848. [CrossRef]

46. Samuel-Nakamura, C.; Hodge, F.S. Metal(loids) in Cucurbita pepo in a uranium mining impacted area in northwestern New Mexico, USA. *Int. J. Environ. Res. Public Health* 2019, 16, 2569. [CrossRef]

47. Brugge, D.; Missaghian, M. Protecting the Navajo people through tribal regulation of research. *Sci. Eng. Ethics* 2006, 12, 491–507. [CrossRef] [PubMed]

48. Pardilla, M.; Prasad, D.; Suratkar, S.; Gittelsohn, J. High levels of household food insecurity on the Navajo Nation. *Public Health Nutr.* 2013, 17, 58–65. [CrossRef] [PubMed]

49. Isaac, G.; Finn, S.; Joe, J.R.; Hoover, E.; Gone, J.P.; Lefthand-Begay, C.; Hill, S. Native American perspectives on health and Traditional Ecological Knowledge. *Environ. Health Perspect* 2018, 126, 125002. [CrossRef] [PubMed]

50. Nation Navajo Nation Environmental Protection Agency (NNEPA). Guidelines for Hauling and Transporting Regulated Water for Human Consumption. 2013. Available online: http://www.navajopublicwater.org/Guideline4Hauling-Transporting_RegulatedWater4HumanConsumption.pdf (accessed on 1 October 2015).

51. Hosen, N.; Nakamura, H.; Hamzah, A. Adaptation to climate change: Does traditional ecological knowledge hold the key? *Sustainability* 2020, 12, 676. [CrossRef]

52. Gomez-Baggethum, E.; Corbera, E.; Reyes-Garcia, V. Traditional Ecological Knowledge and global environmental change: Research findings and policy implications. *Ecol. Soc.* 2013, 18.

53. Pearce, T.; Ford, J.; Cunsolo Willox, A.; Smit, B. Inuit traditional ecological knowledge (TEK), subsistence hunting and adaptation to climate change in the Canadian Arctic. *Arctic* 2015, 68, 233–245. [CrossRef]