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An Adaptive Visual Learning Approach for Waterborne Disease Prevention in Rural West Africa

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AN ADAPTIVE VISUAL LEARNING APPROACH FOR WATERBORNE DISEASE PREVENTION IN RURAL WEST AFRICA

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Depleted water supplies, along with industrial and human waste, are driving a world water crisis that poses a growing risk to food markets, energy production, political stability, and human health (Global Water Security 2012). One obvious example of the this crisis is the more than 1 billion people who obtain their drinking water from contaminated sources (WHO/UNICEF 2006; Clasen et al. 2008). With a projected increase of 1.3 billion people between now and 2050, Africa will add more to the global population than any other world region (Haub and Kaneda 2013). For this research, visual learning design factors were incorporated into water literacy materials in order to study ways in which cultural and societal barriers can be overcome through culture- and gender-appropriate graphics designed to foster visual storytelling in the West African country of Niger. Women were targeted as the study population since they are the primary water fetchers and handlers in sub-Saharan Africa. Eye-tracking technology and GIS tools were used for quantification of the visual design characteristics. Research was conducted in 23 villages along the Niger River, and included 510 interviews, 693 focus group participants, 9 different cultural groups, over 30 hours of audio interviews, and 464 eye-tracking trials. Tobii X2-60 eye-tracking equipment was used in bush maternity wards, medicinal depositories, and mud-brick homes. Eye-tracking data were imported into an ArcGIS platform, where kernel density estimation (KDE) analyses were performed in an effort to compare and contrast the KDE of varying education levels, age groups, ethnic groups, and village types. Spatial autocorrelation analyses were used to evaluate whether the spatial pattern of attribute values (fixation time) was clustered, dispersed, or random. Results from this research suggest that visual communication can be used to overcome low education and cultural barriers for waterborne disease prevention. Using an adaptive visual-learning approach for the research method provided a creative alternative to conventional water-education materials, as most do not consider mother tongue and low literacy. Through visual communication, a novel way has been developed to understand how disadvantaged populations in sub-Saharan Africa visually process water literacy materials.

Chapter 1: Introduction

Water is a complex and vulnerable resource. Temporal, spatial, and quality variations create international challenges for poverty, food security, and health. Global understanding of this vital resource begins with the realization that variability and availability concerns are not just for the inhabitants of developing nations. Water scarcities directly and indirectly affect the world's economy, regardless of affluence or geographic location. Earth is covered with water, but over 97% is salt water, nearly 2% is in polar ice caps, and less than 1% is available and only safe to drink after it is treated (McNulty 2010; Global Water Security 2012). With less than 1% of the world's water available for consumption by over seven billion people, global water demand continues to stress reserves. Myriad adverse implications exist of inadequate access to potable water, and these impacts require extensive and intensive analysis. Depleted water supplies, along with industrial and human waste, are driving a world water crisis that poses a growing risk to food markets, energy production, political stability, and human health (Global Water Security 2012).

One obvious example of the world water crisis is the more than one billion people who obtain their drinking water from contaminated sources (WHO/UNICEF 2006; Clasen et al. 2008). These unsafe water sources are interconnected with diarrheal diseases that kill nearly two million people annually, with the vast majority being children less than five years of age (Mäeusezahl et al. 2009). Waterborne diseases are caused by the ingestion of contaminated water that contains pathogenic microorganisms. Improper sanitation and hygiene further promotes the transmission of pathogens. Eighty-eight percent of worldwide cases of diarrhea (Prüss-Üstün et al. 2008) are directly linked to inadequate water, sanitation, and hygiene (WSH). Regions within South Asia, Africa, and the Middle East, along with countries like Haiti, Cambodia, Laos, and China, are facing dire water quality problems (Cyr 2012; Ma and Adams 2013). The lack of proper sanitation, hygiene, and clean water in these areas fosters environments where water-borne pathogens and communicable diseases cause high mortality rates (Montgomery and Elimelech 2007; Mäusezahl et al. 2009).

With a projected increase of 1.3 billion people between now and 2050, Africa will add more to the global population than any other world region (Haub and Kaneda 2013). Most, if not all, of that growth will be in the countries of sub-Saharan Africa, the region's poorest. Despite global awareness and funding for water and sanitation programs, disease burdens directly associated with inadequate WSH still exist. Every fifteen seconds a child is killed by diarrhea in sub-Saharan Africa (George 2009; Bizzarri et al. 2011). A significant challenge for policymakers is recognizing that water resources are unevenly distributed geographically within Africa's sub-regions. Underdeveloped infrastructure, overexploited supplies, and physical topographies are responsible for differences in water availability and quality between African countries. Widespread poverty constrains a country's ability to address water issues, which further impacts the relationship between water and poverty.

West Africa has some of the lowest access rates to safe drinking water in the world (UNEP 2010). The Niger River Basin, which lies within West Africa, provides water to 11 countries with a total population of 100 million. However, most communities along the river do not have treatment plants for their industrial and domestic wastewater (UNEP 2010). Wastewater from oil refineries and pipelines, coupled with human waste, leads to poor water quality within the basin. One river basin country in particular, the Republic of Niger, obtains nearly 90% of its water resources from the Niger River (UNEP 2010). Niger's Human Development Index (HDI), ranking as last out of 178 countries, reflects the country's worldwide status as one of the poorest in the world. Niger has a life expectancy of 58 years, 1.44 mean years of schooling, and has 89.8% of its population living in multi-dimensional poverty (UNDP 2014).

Niger's water supply deficiencies, and its associated implications, are deeply rooted in poverty. An adult literacy rate of 15% (UNESCO 2012) and a female literacy rate of 9% (Grote and Warner 2010) further illustrate poverty's grip on the nation. Each day in Niger, 33 children (12,000 per year) die from diarrhea caused by unsafe drinking water and improper sanitation (Wateraid 2014). More than 90% (14 million people) of the population does not have access to proper sanitation, and nearly 50% (8 million people) of the population does not have access to safe drinking water (Wateraid 2014; World Bank 2014a; 2014b). Moreover, Niger's lack of infrastructure and education has given rise to 81% percent of the population practicing open defecation (Galan et al. 2013).

Inequalities among hard-to-reach cultural groups, who are disproportionally affected with a high incidence of infectious diseases, originate from water illiteracy and a lack of monetary resources and infrastructure. Health interventions can lead to positive outcomes among target populations in water-education campaigns; however, low-literacy, cultural, and socioeconomic barriers have restricted the implementation and success of interventions among vulnerable populations in sub-Saharan African countries.

Visual learning design, specifically incorporating graphic design to foster visual storytelling, could provide a new approach to water education for target populations.

This research focused on the use of eye-tracking technology to investigate how water educational materials can be enhanced through the use of visual communication: i.e., illustrations, diagrams, and graphic design. Two constraints that are commonly ignored in the development of educational materials for hard-to-reach populations are mother tongue and literacy (Houts et al. 2006). Since there are over 1,000 indigenous languages spoken in Africa (Govender 2005) and adult literacy rates in the region are, on average, below 50% (UNESCO 2012), language and illiteracy present complex challenges to water education campaigns in the region. Communicating through visuals, rather than the written or spoken word, can help educators and aid workers overcome language barriers in developing countries and can improve comprehension among people with limited literacy (Houts et al. 2006). Communicating information visually also supports and reinforces educational content by adding an aesthetic element (Arbuckle 2004) and provoking observer emotion (Curtis et al. 2011).

Prior research in education through graphic design has argued that visual aids should carefully consider designs that connect with existing knowledge from the target population, attract the attention of the target population, hold the population's interest, and present data and information in ways that lead to population adherence (Mansoor and Dowse 2004). Yet, the specific characteristics of visuals that are known to hold interest, attract attention, and present information meaningfully are largely unknown, particularly in regards to visuals related to water-resource education. In short, the use of visuals to educate can be particularly useful when attempting to overcome literacy barriers, but only if the design of such materials is effective at communicating information.

Using ethnic groups in rural West Africa as a case study, this research investigated the characteristics of effective water literacy materials, examining how low literacy observers visually process complex water-related educational materials and the effect this processing has on the interpretation and understanding of presented material. This research evaluated the effectiveness of sanitation and hygiene, water pollution, and point-of-use water treatment technique visualizations to improve observers' understanding of these concepts and to identify the characteristics of instructional visualizations that communicate about them successfully. Most research in the education field has concentrated on the advancement of the discipline through the use of outcomes assessments and interviews (Denzin 2009). In this study, eye-tracking technology was combined with outcomes assessments, interviews, and advanced GIS-based quantitative spatial statistical analyses to advance knowledge in the discipline in new ways. This novel approach to education research advances the discovery and understanding of the ways in which visual communication can be used in informal learning campaigns, not only among rural populations where literacy and language barriers exist but also in the development of educational materials for use in classrooms, textbooks, museums, and science centers. Results from this study help advance the discovery and understanding of the ways in which visual communication can be used in informal learning campaigns among rural populations where literacy and language barriers exist. The results promote water education among groups of people who are categorized as socially disadvantaged.

1.1 Research Questions and Objectives

The following research questions were answered as part of this research:

- What influences effective visual design for gender- and culture-specific water, sanitation, and hygiene interventions in rural West Africa?
- How can visual learning design, eye-tracking technology, and GIS be used to overcome the challenges of water education in low-literacy environments?

The objectives of this research were to:

- work with hard-to-reach cultural groups in rural West Africa in a case study for identifying quantitatively visual design characteristics that communicate effectively about WSH interventions and that promote water literacy;
- use informal learning techniques to engage people through visual communication, leading to the empowerment of women through water education;
- apply visual learning design to investigate and enhance the creation of WSH interventions;
- study visual communication as a tool to overcome literacy and language barriers for WSH interventions; and
- use eye-tracking technology and GIS to quantify and support a design approach for the creation of water education materials in under-represented groups.

This research is innovative and original in scope, not only in producing educational materials, but also in investigating the effectiveness of these materials and revealing the process researchers could use to create educational visuals. The application of eye-tracking techniques can advance the discovery and understanding of the ways in which visual communication can be used effectively in informal learning campaigns. The level of consultative input from within the target population helped measure the study's success. Most published research in this field concentrates on the continuation of previous work by the use of surveys and interviews only. This current work included eye-tracking, qualitative surveys and interviews, and quantitative statistical analyses. In fact, this research was the first to use in-the-field eye-tracking techniques in rural West African villages. Village members, including targeted under-represented groups of women, were involved not only in the research on water literacy visual communication, but also in the creation and dissemination of those materials.

Qualitative interviews and surveys within target populations served as a consultative design approach leading to the eventual creation, implementation, and adoption of water education materials. Future work in the areas of promoting water education and teaching hard-to-reach cultural groups who are categorized as societally disadvantaged can be reproduced in other populations around the world. In short, this work used knowledge as a source of empowerment to create an environment where water literacy communication materials overcame language, cultural and societal barriers, and gave rise to interventions that are simple, affordable, and sustainable.

Chapter 2: Literature Review

Despite recent awareness and funding for water and sanitation programs worldwide, disease burdens directly associated with inadequate water, sanitation, and hygiene still exist. Disparities among hard to reach cultural groups, who are disproportionally affected with high incidences of infectious diseases, stem from water illiteracy and a lack of resources. Health interventions can be successful among target populations in water-education campaigns; however, low-literacy, cultural, and socioeconomic barriers have limited the implementation and success of interventions among vulnerable populations in sub-Saharan African countries. Visual learning design factors, which incorporate graphic design to foster visual storytelling, can provide a new approach to water education materials for target populations.

2.1 Water, Sanitation, and Hygiene

Sub-Saharan Africa is one of the poorest regions in the world (Sachs et al. 2004). Harsh political, social, economic, and environmental factors combine to create communities mired in poverty and debt. Regardless of genealogy or birthrights, people in sub-Saharan Africa experience life far differently than most. At the beginning of the 21^{st} century, 26 of the 49 least-developed countries in the world by the United Nations' classification were in sub-Saharan Africa, while 33 countries were considered low-income according to World Bank country classifications. Of those 33 countries, the population-weighted average annual income was $271 per person, or a mere $0.74 a day (Sachs et al. 2004). Fortunately, world poverty has been decreasing over the last several decades through foreign aid, capacity building, and resource management. Additionally, new standards for measuring poverty levels have emerged and allow for more accurate needs assessments (Chen and Revallion 2004; Fosu 2015).

Although many countries have made notable advances in health initiatives, and the global population is living longer and getting older, drastic variations in health can be found easily in the comparison of developed and less developed nations. Overwhelmingly, in poor, developing countries, health needs exist that can be traced back to the roots of inadequate water quality, improper sanitation, and poor hygiene behaviors (Montgomery and Elimelech 2007; Bartram and Cairncross 2010; Mara et al. 2010). The lack of proper sanitation, hygiene, and clean water in these areas foster environments where water-borne pathogens and communicable diseases cause high mortality rates (Montgomery and Elimelech 2007; Mäusezahl et al. 2009). As noted by Curtis et al. (2005), most child mortality occurs in countries that are low and middle income: i.e., the world's poorest populations.

The burden of disease becomes a major contributor to the self-perpetuating cycle of poverty through the association of inadequate water, sanitation, and hygiene (WSH) to the poor and disadvantaged (Bartram and Cairncross 2010). Transmission pathways of diseases resulting from WSH are entangled with one another and interrelated. Where one finds inadequate sanitation, poor water quality can be found. Where one may find improper hygiene, poor sanitation can be found. These transmission pathways can be independent of one another or they can amalgamate, complementing one another, and becoming even more detrimental to the population (Pruss et al. 2002). The diseases associated with poor sanitation and poverty account for nearly 10% of the global burden of disease (George 2009; Mara et al. 2010). Also, income inequality among vulnerable populations stimulates environments that foreign investors are less likely to invest in and, thus, undermines a country's future economic growth. Moreover, foreign companies are less likely to invest in countries with high disease prevalence rates because of the threat to the firm's own workers, the prospect of high labor turnover, and the potential human loss of life (Laxminarayan and Jamison 2010).

Infectious diarrhea is considered the largest contributor to the global disease burden from WSH. Infectious diarrhea, however, can also be transmitted by food and air (Pruss et al. 2002). Regardless, this burden is largely preventable through interventions and health initiatives. In the developing world, the disease burden can indirectly affect school performance and delay entry into the job market (Bartram and Cairncross 2010). The societal and economical costs associated with infectious diseases in developing nations can be assessed from the sum of treatment for infection, income loss from working days missed, school absenteeism, morbidity, and mortality (Murray et al. 2012; Murray and Lopez 2013). Diarrhea kills a child every fifteen seconds (Shimp and Andrews 2013; Rehydrate 2015). Further, the number of children who have died from diarrheal related illnesses in the last decade exceeds the total number of people killed by all wars combined since World War II (George 2009).

Waterborne diseases are caused by the ingestion of contaminated water that contains pathogenic microorganisms. Improper sanitation and hygiene further promotes the transmissions of pathogens. According to Prüss-Üstün et al. (2008), eighty-eight percent of worldwide cases of diarrhea are directly linked to inadequate water, sanitation, and hygiene. Most infectious diseases that are categorized as diarrhea related are transmitted via the Fecal-Oral route (Pruss et al. 2002). Cholera, typhoid, amoebic and bacillary dysentery, infectious hepatitis, and giardiasis are just a few of the more severe types of diarrheal diseases. The Fecal-Oral route of transmission occurs when an animal or human unknowingly ingests bacteria or viruses from the stool of an infected host through the mouth. This can occur as small fecal particles contaminate water, food, hands, and clothing, and then are ingested. Infection can also occur from bathing and washing with contaminated water. In addition, improper hygiene practices in the consumption of food that has not been prepared properly and that is infected with pathogens will result in transmission (George 2009).

Repeated diarrhea from WSH diseases leads to malnutrition and a greater vulnerability to other infectious diseases. Thus, malnutrition has an indirect affect, as well as a direct affect, on the burden of disease. As noted by Prüss-Üstün et al. (2008), the total number of deaths caused directly and indirectly by malnutrition induced by unsafe water, inadequate sanitation, and insufficient hygiene is 860,000 annually among children under five years of age. Unclean hands, improper handling and preparation of food, open defecation, using contaminated water for drinking, bathing, and washing, all are factors that can be altered and lead to a change in the health landscape for people living in sub-Saharan Africa. Education and outreach efforts can be useful tools for communicating important health information and help alleviate the effects diarrheal diseases have on individuals and rural populations.

2.2 Health Interventions

Interventions and health promotion campaigns are used in developing nations in the attempt to reduce the incidence of mortality and morbidity associated with WSH. According to Fewtrell et al. (2005), water interventions are those that include the improvement of water quality via the removal of microbial contaminants, either at the original source or at the household, while sanitary interventions include those that involve proper human and animal waste removal. Hygiene interventions include the encouragement of specific behaviors and health education campaigns that promote actions and habits key to positive measurable outcomes: e.g., hand washing with soap after defecation, boiling water before drinking when appropriate, and using a pit latrine for defecation rather than open defecation (Fewtrell et al. 2005). The World Health Organization (WHO 2007) estimates that 94% of diarrheal cases are preventable through modifications to the environment, including interventions to increase the availability of safe water and to improve sanitation and hygiene behaviors. There are many aspects to consider when making decisions on which specific intervention might best serve a target population: social, physical, and biological (Fewtrell et al. 2005; Curtis et al. 2009). Social environmental factors are those that influence the target population (e.g., religion, national regulations, and culture), physical environmental factors are those relating to geographic location, climate, and anthropology (e.g., water and sanitation infrastructure and availability), and biological environmental factors are those associated with other animals and plant life (e.g., food, domestic animals, and diseases). Any proposed intervention should be examined for its simplicity, affordability, sustainability, and acceptability among the target population in order to be applicable (WHO 2007).

2.2.1 Boiling Water

A substantial portion of the world's population must rely on contaminated water for everyday needs. In fact, over one billion people obtain drinking water from unsafe sources (WHO/UNICEF 2006; Clasen et al. 2008a). Efforts to prevent mortality and morbidity associated with unsafe water supplies have led to interventions for the treatment of water at the household level. Point-of-Use, or Household Water Treatment, interventions have the ability to deactivate bacteria, viruses, and protozoa. Boiling or heating water for its purification is the oldest and most used point-of-use water quality intervention (Sobsey 2002; Sodha et al. 2011). Boiling water is the standard by which all other water treatment interventions is measured, due to its highly effective treatment efficiency in destroying bacteria, viruses, and protozoa (Rosa and Clasen 2010). The key to its efficacy is based on two variables: temperature and time. Depending on the altitude, the boiling point must be reached and sustained for at least 1 to 5 minutes at a rolling boil (Sobsey 2002; Clasen et al. 2008b). A rolling boil is used often in intervention campaigns due to the lack of temperature monitoring devices outside of laboratory settings (i.e., thermometers). If the boiling point is reached, boiling has inactivated all bacteria, viruses, and protozoa present in the water (Sobsey 2002; Clasen et al. 2008b). A recent study among vulnerable populations in Indonesia assessed the effectiveness of boiling water as a point-of-use treatment technique and found a 1.9-log reduction for *Escherichia coli* contamination (Sodha et al. 2011). Studies in India and Vietnam (Clasen et al. 2008a;b) and Guatemala (Rosa et al. 2010) determined 2.1-, 1.5-, and 0.9-log reductions, respectively.

Boiling water is a viable point-of-use treatment technique; however, it has limitations that lead to disparities among laboratory and field results. These disparities can be attributed to culture, lack of knowledge, improper handling and recontamination of water, not following boiling point protocols, and limited access to resources and fuel (Rosa and Clasen 2010). Among 67 national surveys for low and middle-income countries Rosa and Clasen (2010) found that an estimated 1.1 billion people reported treating their water using a point-of-use technique, with boiling being the most prevalent method used by 598 million people. Despite the risk of infectious waterborne diseases, boiling water at the household level is unfeasible for many of the world's poorest cultural groups, due to lack of resources geographically and high costs associated with resources (wood, pots, fuel) where available (Sobsey 2002). Thus, poverty-stricken regions, such as sub-Saharan Africa, are most likely to rely on unsafe water supplies (Blakely et al. 2005), but also less likely to practice point-of-use treatment (Rosa and Clasen 2010).

2.2.2 Solar Disinfection

One of the largest renewable energy resources found in sub-Saharan Africa is solar radiation. According to the National Solar Power Research Institute, most African countries receive 325 days of sunlight a year and daily solar radiation between 4 kWh and 6 kWh per square meter, which correlates to a high generating capacity potential (Satre-Meloy 2014). This resource has shown promise among vulnerable populations in its efficacy as a point-of-use strategy (Rose et al. 2006). Solar disinfection (SODIS) is a point-of-use technique that takes advantage of the abundant energy found in sunlight (Kehoe et al. 2001). As determined by Agrawal and Bhalwar (2009), solar disinfection has a low cost investment: approximately US$8 based on a 500 Rupee conversion rate. Solar disinfection uses the sun's energy to deactivate bacteria, viruses, and protozoa. Ultraviolet and infrared radiation emitted from the sun work together in a synergistic inactivation process (McGuigan et al. 1998) and can have a 1- to 6-log microbial efficacy (Dejung et al. 2007) dependent upon time/radiation application and pathogen type. UV-A radiation (UV-A, 320-400nm) interacts at the molecular level of the pathogen and leads to cell death, while infrared radiation is absorbed by the water and increases the temperature (Metzler et al. 1994). Microorganisms are sensitive to heat and can be inactivated by this alone. Water does not have to be boiled to kill microorganisms; heating water to an elevated temperature (55°C) over an extended period of time has the same effect as boiling (Metzler et al. 1994; Joyce et al. 1996).

Despite widespread global promotions of SODIS, peer reviewed field studies conducted on its efficacy are minimal. Three studies, in particular, displayed discrepancies among results. The first, a study in Kenya among Maasai children less than 6 years of age, documented a 16% decrease in diarrheal morbidity from water that was treated by solar radiation (Conroy et al. 1996). Second, in Southern India, a 40% reduction in the incidence and severity of diarrheal morbidity was observed among children less than 5 years of age in an urban slum using SODIS (Rose et al. 2006). Lastly, in Bolivia, a cluster-randomized trial study yielded only moderate reduction, not statistically significant, in diarrhea incidence among children (Mäusezahl et al. 2009).

Discrepancies among laboratory efficacy compared to field effectiveness illustrate the challenges associated with SODIS and how well it translates among various cultures. One of the greatest strengths of SODIS is also its biggest limitation: sunlight. SODIS is dependent on the amount of sunlight available. Radiation from the sun varies in intensity from one geographical location to another depending on season and time of day. In addition, poor weather conditions during treatment events can minimize the effect of SODIS. Other limitations include high turbidity in water that can block solar radiation, extended treatment time required for proper water treatment, and limited sample volumes of 2 liters or less (Meierhofer and Landolt 2009; McGuigan et al. 2012). Implementation requires accurate communication and training by a specialist who is aware of misinterpretations and confusion at the point of use (Dejung et al. 2007).

Although points-of-use intervention studies have demonstrated success in the reduction of disease transmission, inconsistencies among studies have been documented in Kenya (Conroy et al. 1996), India (Rose et al. 2006), and Bolivia (Mäusezahl et al. 2009). These inconsistencies could be attributed to a lack of sanitation in the study area. Evidence suggests that the effectiveness of point-of-use water quality interventions depends on the sanitation level of the target community (Esrey 1996; Eisenberg et al. 2007). Furthermore, communities that lack basic sanitation can experience minimal impact from water quality improvements regardless of the volume of safe drinking water available as sources become re-contaminated. Gundry et al. (2004) suggested that point of use interventions had greater impacts on the incidence of diarrheal morbidity in areas that had adequate sanitation. Gundry et al. (2004) explained further that this could be due to the restriction of fecal-oral transmission pathways associated with fecal matter around the household compound and community defecation areas. If a transmission pathway maintains diarrheal disease, single pathway interventions will have minimal benefit (Eisenberg et al. 2007); an intervention will only be successful if all transmission pathways are eliminated.

2.2.3 Open Defecation and Pit Latrines

According to the *Progress on Sanitation and Drinking Water Report*, 15% of the global population, over 1 billion people, practice open defecation; additionally, 2.5 billion people do not use an improved sanitation facility (WHO/UNICEF 2013). Open defecation refers to the act of defecating by adults or children, in which excreta are deposited (directly on the ground or after being covered by a layer of earth) in the bush, field, beach, or other open area (Galan et al. 2013). This also includes defecation wrapped in temporary material and discarded or discharged into a drainage channel, river, sea, or other water body. Excreta transmit an extensive number of infectious diseases (Montgomery and Elimelech 2007; Bartram and Cairncross 2010). Improper disposal of waste leads to myriad pathogen transmission possibilities through the fecal to oral route (Pruss et al. 2002). Improved hygiene practices by entire communities (Sanan and Moulik 2007), including the use of sanitary toilets, can break this cycle of disease transmission. For perspective, 1 gram of feces from an infected person can contain up to 10^6 viral pathogens, 10^6–10^8 bacterial pathogens, 10^4 protozoan cysts or oocysts, and 10–10^4 helminthic (intestinal worm-like parasites) eggs (George 2009; Mara et al. 2010); individuals who live in areas with inadequate sanitation ingest an estimated 10 grams of fecal matter each day (George 2009).

A study conducted by Galan et al. (2013) revealed that open defecation prevalence is varied and widespread in sub-Saharan Africa. The paucity of countries making progress in the reduction of open defecation prevalence contrasts with the abundance of diarrheal disease pathways in sub-Saharan Africa. Improved sanitation for impoverished communities begins with a reduction in open defecation and leads to an eventual open-defecation-free environment. Galan et al. (2013) also revealed that there is no association between a country’s stance on open defecation and open defecation reduction, regardless if the country incorporated a national sanitation policy or allocated a budget to alleviate open defecation prevalence. Higher per capita GDP and economic growth also showed no relationship with the reduction in open defecation prevalence.

Foreign aid disbursement for water supply and sanitation, however, had a strong relationship with open defecation reduction in low-income countries.

Interventions associated with open defecation can be difficult to achieve due to the complexities that surround sanitation. Economic, social, and health components for adherence are challenging to disaggregate from one another. Economic aspects of open defecation interventions commonly center around affordability, as rural communities and individuals install whatever sanitation system is affordable and upgrade when finances permit (Mukherjee 2012). A large portion of the global population uses open defecation because it has no other choice; four in ten people have no access to any latrine, toilet, bucket, or box in which to defecate (George 2009). Social interventions are centered on the motivations and behaviors to open defecation. In some cases, even with no major constraints in terms of ability and opportunity to change defecation practices, individuals' motivations to change behavior are weak and they continue to use open defecation (Mukherjee 2012). Health components of open defecation interventions involve disease theory knowledge, which can be abstract to diverse cultural groups and does not ensure behavior change (Mukherjee 2012). Although 90% of most sanitation-related budgets are directed to water supply, providing cleaner water only reduces instances of diarrhea by 16-20%. Moreover, proper disposal of human excreta can reduce diarrhea by nearly 40% (George 2009).

Open defecation-free status is the fundamental first step for improved sanitation, and current trends indicate most sub-Saharan African countries will not achieve an open-defecation-free status in the foreseeable future (Galan et al. 2013). The need for effective strategies in the reduction of open defecation cannot be overemphasized, as modern sanitation has added twenty years to the average human lifespan (George 2009). A new approach that is gaining momentum among vulnerable populations, Community Led Total Sanitation, involves the use of local, sustainable, and affordable sanitation options, from a village/community perspective, instead of subsidies from the government (Sah and Negussie 2009; Kar and Milward 2011). The context of basic human dignity unites the community to commit to using sanitary latrines and hygienic behavior with a zero subsidy approach rather than providing funds to construct latrines. Community Led Total Sanitation empowers communities to conduct their own analysis of open defecation, where members become actively involved in the management of their own sanitation and hygiene. Community Led Total Sanitation uses social communication and promotes communities to take action to become open defecation-free, and approaches developed in health education, such as behavior change communication and social marketing, to encourage and sustain behavior change (Devine and Kullmann 2011). Over 14,000 villages in Ethiopia (Galan et al. 2013) and 210,000 individuals in Zambia (Kar and Millward 2011) have become open defecation-free using the Community Led Total Sanitation approach.

2.2.4 Hand Washing with Soap

In 2011 and 2012, 74% of the total burden of diarrhea and pneumonia mortality for children occurred in Southeast Asia and Africa; the highest incidence of child mortality occurred in sub-Saharan Africa, where 6.5 million deaths occurred, 10% of which were attributed to diarrhea (Walker et al. 2013; Mattioli et al. 2014). When health outcomes become more severe, the global burden becomes more concentrated in the countries with the highest mortality and morbidity (Walker et al. 2013). Hand washing after defecation and before preparing and eating food can reduce the transmission of infectious diarrheal diseases (Curtis and Cairncross 2003; Ejemot-Nwadiaro et al. 2012). For example, Shahid et al. (1996) observed a reduction of 47-73% of diarrheal incidence in Bangladesh for all age groups studied. Curtis and Cairncross (2003) found that interventions to promote hand washing with soap were associated with a decrease in risk of diarrheal disease of 47%. Ejemot-Nwadiaro et al. (2012) observed a one-third reduction (32% to 39%) in diarrhea morbidity by hand washing with soap.

WSH health interventions in developing countries were examined in a World Bank/World Health Organization Disease Control Priorities Project and found to be highly cost-effective (Fewtrell et al. 2005). Health interventions that included hygiene promotion were the most cost-effective of all major disease-control interventions, at US$5 per Disability Adjusted Life Year (DALY), with sanitation promotion at an estimated US$10 per DALY (Bartram and Cairncross 2010). The Disability Adjusted Life Year (DALY) for a disease is the measurement of the gap between the current health status of a population and the ideal health status for the same population that lives free of disability and disease (Pruss et al. 2002; Montgomery and Elimelech 2007; Murray et al. 2012; Murray and Lopez 2013). Although hand washing with soap is one of the most cost-effective interventions for developing countries, it is not common among vulnerable populations at key junctures, such as before handling food and after defecation.

An eleven-country review of hand-washing behaviors conducted by Curtis et al. (2009) determined that only 17% of those studied (4,099 participants) washed their hands with soap and water after defecation, while 45% of the 4,099 participants used only water to wash their hands after defecation. For those who hand washed with soap, the occurrence was highest after defecation and before the feeding of children. Curtis et al. (2009) categorized hand-washing behaviors as habitual, motivated, and planned. Habitual behaviors are those that are learned and become an automatic behavior from a particular cue. Planned behaviors are associated with the pursuit of long-term objectives (e.g., health), while motivated behaviors are used for short-term rewards. The motivations revealed by Curtis et al. (2009) included disgust, nurture, status, affiliation, attraction, comfort, and fear.

Diarrheal mortality and morbidity is largely a disease of the impoverished, and soap most commonly is not found among these populations. Even when soap is readily available, hand washing with soap is not a common practice among target populations with high mortalities and morbidities associated with diarrhea (Curtis et al. 2009) due to deeply rooted cultural and societal hygiene practices that are often difficult to change. Yet, hand washing with water alone could be a first step to total hand washing, similar to an open-defecation-free status as the integral first step towards total sanitation (Curtis et al. 2009). Microbiological studies have demonstrated that washing hands with water alone reduces the concentration of various types of bacteria on hands (Lowbury et al. 1964; Ansari et al. 1989).

Health interventions can be used by hard-to-reach populations in the effective prevention of disease transmissions. However, in order to be effective as a WSH intervention, individuals and communities pursuing improvement in WSH should consider all three categories individually and as a whole. Point-of-use treatment techniques can improve water quality at the household level. Pit latrines can be seen as a first step to an open-defecation-free status. Hand washing with soap can inhibit the fecal to oral route of disease transmission. Water, sanitation, and hygiene interventions involve individuals taking action and assuming responsibility for the improvement of their personal health. Communicating protocols is integral for WSH interventions success.

2.3 Women's Role and Empowerment

A World Bank evaluation of 122 water projects found that a project was six to seven times more effective when women were involved with WSH projects than when they were not (Fisher 2006). The projects evaluated were of various types focusing on the effect and benefits of placing women at the center of planning and implementation of WSH programs. Project locations included countries in Africa, Indonesia, India, Ukraine, Jordan, Pakistan, Nepal, Nicaragua, Jamaica, Sri Lanka, Malaysia, Tibet, Morocco, Philippines, Dominican Republic, El Salvador, and Australia. Women are vital in WSH project awareness campaigns, as they are responsible for water handling and storage. African women are also household caretakers and cope with the additional burden of caring for members who become sick as a result of unsafe water, poor sanitation, and improper hygiene behaviors (Fisher 2006). In addition, women are cognizant of village knowledge and any problems associated with common habits. Therefore, they are the center of education for their families and other community members in transmitting the benefits of the use of safe water, proper sanitation, and good hygiene practice.

Involving women in WSH intervention campaigns can benefit the programs' implementation and success. Women's groups have proved to be one of the most effective entry points (Ogunlela and Mukhtar 2009**)** for initiating activities and reaching poor households. In efforts to reach and engage the poor, issues and constraints related to participation can be gender-specific (Ogunlela and Mukhtar 2009), as men and women play different roles, have different needs, and face different challenges on a number of issues and at different levels.

Water fetching in sub-Saharan Africa primarily is the responsibility of women and children (Bardasi and Wodon 2006; Ray 2007). Time-use issues have strong gender dimensions, as African women spend long, arduous days fetching water, working in fields, cooking, and caring for their households (Charmes 2006; Ray 2007); the task of providing water for each household is also predominantly a female one. In fact, it is estimated that 40 billion hours per year are spent fetching water in sub-Saharan Africa (Ray 2007; Stanford 2012; Pickering and Davis 2012); this estimation is mostly accounted for by women. The health consequences of not having clean water readily available and, thus, the physical act of carrying water to and from the source, is of particular relevance to women (Bardasi and Wodon 2006; Charmes 2006; Kes and Swaminathan 2006; Ray 2007). Distances traveled and time spent on water collection duties add up to several miles and hours per day. Water containers can weigh up to 40 pounds, and are placed on the necks, arms, and shoulders of the carriers (Ray 2007). Dry seasons in rural India and Africa cause women to spend 30% or more daily energy just in water collection (Ray 2007). Time allocated to water duties is also time missed in the classroom and in working. The lack of access to an improved water source, or the difficulties of obtaining access to unreliable water sources, has been called "time poverty" and is a major issue for women and children (UNDP 2015; Ray 2007).

Over one billion people lack access to the minimum quantity of water needed for basic health and hygiene (Ray 2007); this number is most likely an underestimate when including population growth and rural households. The lack of reliable access to safe water and improved sanitation could be a major contributor to gender inequality in education and its associated opportunities (Blackden and Wodon 2006; Ray 2007). Educating women and children would empowered them with knowledge about the resources they desperately need. Education should lead to improved water, sanitation, and hygiene behaviors. Empowered women should also make better decisions and play active roles in their homes, villages, and community. As noted by Roudi and Moghadam (2003), the benefits for empowered women are better education, decreases in infant and child mortalities, and improved family health.

2.4 Communicating Water Education

The strength of a WSH intervention lies in its eventual use for the alleviation of mortalities and morbidities. Strategies that aim to change community practices and household and individual behaviors in ways that are sustainable should be considered when choosing intervention specifics. The Integrated Behavioral Model for WSH (Dreibelbis et al. 2013) offers a structure for designing and evaluating behavior change interventions based on three dimensional factors: contextual, psychosocial, and technological. The contextual dimension represents the characteristics that surround the targeted area, individual, or environment (i.e., access to markets, products, and resources; wealth, education, gender, and employment; climate and geography; division of labor and available space). The psychosocial dimension consists of the responsive stimuli that are commonly found in behavior change strategies (i.e., disgust, nurture, motherhood/caretaking, knowledge, leadership/advocacy, aspirations, collective and personal efficacy, and outcome expectations), and the technological dimension represents the physical product, or technology, component (i.e., location of product, availability, ease of use, individual vs. collective ownership, maintenance, costs, value, weaknesses and strengths, and effectiveness of routine use). As noted by Dreibelbis et al. (2013), the success of interventions for the improvement of WSH practices rests on the ability to maintain behavior change at the individual, household, community, and structural levels. The Integrated Model offers a framework for guiding WSH technologies and behaviors in a population.

As noted in the WSH Integration Behavioral Model, there are many variables that can determine an intervention's success or failure. WSH health interventions are multifaceted, involving various forms of communication to educate individuals and communities in protocols and behaviors. Two constraints that are commonly not mentioned, or considered nearly enough, in WSH intervention and health promotion are mother tongue and literacy. Mother tongue refers to the language a person has spoken since birth, the local/familiar language, or the language of a local community that is best known to a child (Alidou et al. 2006). Since there are over 1,000 indigenous spoken languages in Africa (Govender 2006), language and illiteracy create evident challenges to water education campaigns and health promotions. According to the United Nations Educational, Scientific, and Cultural Organization (UNESCO 2012), some of the lowest literacy rates are found in sub-Saharan Africa. In fact, in 2012, adult literacy rates were below 50% in 14 nations (many of which located in Africa): Afghanistan, Benin, Burkina Faso, Central African Republic, Chad, Côte d'Ivoire, Ethiopia, Guinea, Haiti, Liberia, Mali, Mauritania, Niger, and Sierra Leone (UNESCO 2012). As seen in sub-Saharan Africa, regional averages can mask educational disparities stemming from rural poverty;

the adult literacy rate ranges from 15% in Niger to 95% in Guinea. Globally, 24% of all illiterate adults live in sub-Saharan Africa (UNESCO 2012).

Of those that can read, the understanding of key concepts in water literacy can be lost if the mother tongue is not included. Because of these challenges, it is often difficult to find materials specifically created for hard-to-reach cultural groups. As noted by Alidou et al. (2006), development in Africa relies heavily on knowledge and information from foreign sources. Most often, this knowledge and information comes to Africa through languages that are not indigenous to the continent. Communication can only take place through the use of languages mastered by the people (i.e., mother tongues, regional, or national languages). In order for economic development to be sustainable in Africa, it has to be designed and implemented primarily in local indigenous languages. Rather than instructing in a foreign language, using the mother tongue as a language of instruction enables the community and individuals to participate more, creating an environment that integrates the culture (Alidou et al. 2006).

2.4.1 Visual Communication

Using visual communication to overcome the barriers associated with language in developing countries can improve communication where attention, comprehension, and adherence are vital. Visual communication includes pictures, illustrations, diagrams, pictograms, and figures (Morris and Stilwell 2003; Carstens 2004). This approach could become indispensable if adopted into WSH interventions, as it has been successful in the pharmacotherapy field (Dowse and Ehlers 1998; Katz et al. 2006; Sorfleet et al. 2009). Most, if not all, target audiences can benefit from pictures used in health communication, but people with low language and low health literacy are likely to benefit the most (Houts et al. 2006). Furthermore, working with instructors and students who speak different languages can compound confusion (Dowse and Ehlers 2001; Arbuckle 2004). Visual communication increases adherence to medical instructions when accurate communication with patients is key in promoting compliance and ensuring positive health outcomes (Houts et al. 2006; Katz et al. 2006; Sorfleet et al. 2009). Moreover, visual communication has positively assisted with communicating about medicinal labels using storyboard approaches; this suggests the usefulness of separating fundamental elements into components that flow like a story and offer low-literacy learners a less demanding environment in effective visual communication (Sorfleet et al. 2009).

Visual communication also supports and reinforces educational materials by adding an aesthetic element. Visual stimuli that are culturally appropriate attract attention that is commonly found in decorative elements of cultural clothing, household items, and ceramics (Arbuckle 2004). Illustrations can incite emotion by communicating meaning across different languages and cultural contexts. Cultural relevance can play an important role in comprehension, since it includes the skills, attitudes, beliefs, expectations, and values socially learned by the set of individuals in a population or community (Houts et al. 2006; Curtis et al. 2011). Culture can affect hygiene behaviors that are adopted by groups and individuals through the power of norms and manners. In addition, group culture can be a product of the biases of individual brains through predispositions to take on board certain ideas and not others (Curtis et al. 2009). As aforementioned, disgust is one of the responsive stimuli of the psychosocial dimension found in the Integrated Behavioral Model for WSH and is often a target of behavior change strategies (Dreibelbis et al. 2013). Information about what is disgusting is vital to individuals because it can inform about how to avoid disease. Individuals will pay attention to such information and will preferentially pass it on to other individuals within the community.

As Mansoor and Dowse (2004) noted, being culturally sensitive in the creation of health education material is important; this includes using familiar objects, symbols, colors, landscape, environment, buildings, style of dress, animals, and people. Moreover, the target audience should be involved in the development of educational materials as cultural representatives, since this affords valuable insights into the most appropriate, culturally acceptable images to use. The importance of using culturally appropriate and country-specific pictorial material to relay information in low-literate populations cannot be overemphasized (Dowse and Ehlers 1998; 2001; Mansoor and Dowse 2004). A major focus of the research conducted by Mansoor and Dowse (2004) was the creation of a cultural-specific medicine label sequence that incorporated clear, simple, and culturally appropriate images. The researchers found the involvement of representatives of the target population essential in all aspects of the design process through focus group discussions and quantitative assessments among the target population. Furthermore, the researchers determined the modifications and refinements, although time consuming, costly, and labor intensive, were unavoidable if positive measurable outcomes were desired (Mansoor and Dowse 2004). In addition, Hämeen-Anttila et al. (2004) stated that developing and testing pictograms within the target population before use plays an important role in achieving the best possible learning outcomes.

In order to be successful at communicating information, visual aids should be designed considering four processes: connect with existing knowledge from the target population (individual or group), attract the attention of the target population, hold the population's interest, and present the data and information in ways that lead to population adherence (Mansoor and Dowse 2004). When an artist from a different culture designs images that are indecipherable to representatives from another, the problem is commonly due to culture-based misinterpretation rather than cognitive difference. Mansoor and Dowse (2004) offered the following guidelines when designing pictograms for health promotions: collaborate with the target population and gain insights into their knowledge, beliefs, and attitudes that are attributed to their culture; use familiar objects, symbols, clothing, landscapes, environments, and people; design simple, realistic pictures with limited content while using background space appropriately; and pre-test new visual aids in the target population.

When producing communication documents, it is important to be cognizant of the skill level and needs of the target audience. Research-based design heuristics provide guidelines for designing the textual elements (content, structure, style) and the graphic elements (visuals, typography, color, and layout) for low-literacy public information documents (Morris and Stillwell 2003; Carstens 2004). Morris and Stillwell's (2003) research focused on providing technical and scientific agricultural education materials for illiterate South African farmers. Carstens (2004) aimed to give an overview of the theories that describe the ways in which low-literate populations, in particular African audiences, process and react to printed information. These theories were then referenced with research-based principles and best practices for designing public information documents. Carstens' (2004) work provided a comprehensive set of design heuristics for low-literacy public information materials. These recommendations were interconnected with the intended effects of how low-literacy populations process verbal and visual materials. Results of these studies were used in the development of water education materials for this research. Carstens (2004) provided the following textual heuristic guidelines for reading comprehension and visual literacy:

- limit the number of messages on materials to one major theme in order to enhance comprehension and recall;
- ground the content to the prior knowledge of the intended audiences and their information needs to stimulate motivation, comprehension, and recall;
- make the message applicable to real-life situations to create personal relatedness;
- reduce the amount of information to the essential facts, but keep in mind the thematic complexity of the subject;
- provide information about technical data and group affiliations in order to increase persuasiveness through source credibility;
- data and information should be evidence-based and current, which supports ethical and educational contexts;
- make audiences feel emotion (e.g., fear, disgust, moral, rationale) in order to stimulate recall and attention;
- create materials that are tailored for geographic regions of a country, and appropriate to the age, gender, educational level, culture, socioeconomic status, and lifestyle of the target audience in order to increase motivation and comprehension by evoking cultural framework;
- arrange content in logical steps and actions to facilitate comprehension;

- provide examples when using technical terms and ideas to facilitate comprehension; and
- rewrite and conceptualize information in a language and style appropriate to the specific cultural group or community for which the educational materials are intended, to enhance comprehension by connecting the audience to existing cognitive models.

In addition, Carstens (2004) offered the following graphical design heuristics:

- optimize the visual perception of the audiences by being aware of their sensory input level and draw them to the content through the use of visuals;
- use pictures to illustrate the key points in educational materials for explanatory and instructional purposes in order to enhance comprehension and recall;
- use visuals that reflect cultural images (objects, style of dress, and buildings) to increase motivation and facilitate comprehension;
- use visual cues (e.g., arrows, color, underlining, magnifying) to direct eyes to key points to optimize visual perception by enchaining acuity;
- keep images free of clutter and distraction, and remove detail from the background (use negative space) to focus on key elements so as to facilitate encoding and comprehension;
- create an appealing layout to attract and keep attention;
- separate texts and graphics through the use of white space to help decrease cognitive load through the limitation of information given at one time;
- color must be used to attract and enhance and not distract from the message;

- do not overuse colors in order to affect attention and perception;
- use color for queuing and filtering purposes, such as the identification of key points of the content, highlighting, warnings, and preferred actions that help to reduce cognitive load and enhances understanding; and
- pretest color choices on target audience members, as colors can elicit positive and negative connotations in particular cultures that affect emotional appeal and motivations to follow the advice given.

Research conducted among literate and low-literate populations in South Africa for HIV/AIDS education visuals provided specific insights for WSH intervention approaches (Carstens et al. 2006). The researchers determined that the interpretation of abstract items was problematic for both literate and low-literate populations; however, low-literate respondents displayed more difficulty than expected. In addition, Carstens et al. (2006) provided explanations for the use of symbols, abstract elements, and pictorial metaphors as they pertain to respondents' recognition and interpretation success. Speech and thought balloons are difficult for low-literacy audiences, since metaphors are difficult when culture-specific knowledge is required. Results of this study suggest designers utilize the human body in expressive ways to construct abstract meaning; the researchers state that all humans have comparable experiences associated with bodily expressions regardless of literate cognition. Interpretation problems can occur when cognitive load is high because visuals are too complex. As a result, Carstens et al. (2006) recommended that HIV-educational materials use simple, low-literacy materials that have clear graphics, regardless of audience reading skills. Further, according to the authors, designers should develop documents at a 5th-grade level and contain colorful, culturally relevant visuals, as well as negative (white) space.

Low-literacy, socioeconomic, and cultural barriers are impeding the water education knowledge bases among hard-to-reach populations. Using visual learning design techniques that incorporate graphics, visual instructions, and technical illustrations in the creation of water education materials can be effective in overcoming these barriers. In particular, abstract scientific concepts pertaining to health interventions for WSH include boiling water, solar disinfection, non-point source pollution involving open defecation, and hygiene behaviors. WSH interventions that promote and encourage practices for the reduction of disease transmission pathways should be communicated in ways that maximize the target audience's understanding and adherence. In order for WSH health interventions to be sustainable, educational materials should embody culturally specific and formative research-based methods and applications.

2.5 Eye-tracking

Eye-tracking is the quantitative identification of an individual's eye movements and their characteristics (Mayer 2010). By tracking an individual's eye movements, researchers are able to determine where a subject is looking, the gaze duration, and the visual attention path. Eye-tracking research provides novel methods for data collection, offering insight into the ways in which subjects view and interact with their environment. Using visual physiology and specialized equipment, scientists have discovered ways that the human eye interacts with cognition (Mayer 2010), attention (Tsai et al. 2012), and behavior (Granka et al. 2004; Buscher et al. 2009). In user-experience research, eye-tracking allows researchers the ability to comprehend the complete and complex user experience, even that which users cannot describe or explain (Bergstrom 2014). Effective graphics are fundamental for understanding intricate information and completing tasks that are difficult to learn. Eye-tracking methods can be used to measure graphical effectiveness and provide a better understanding of the scanning strategies of individuals. Furthermore, eye-tracking can be used to reveal the ways gestalt principles of design influence the order of visual attention (Djamasbi et al. 2010; Bergstrom 2014).

For over a century, eye-tracking has been used in studies that include cognitive processes for reading, visual search, face recognition, and scene perception (Rayner 1998; Galesic et al. 2008; Bojko 2013). The tracking of eye movements began in the 1800s (Bojko 2013) in the field of reading research. Yet it was not until 1947 that the first application of eye-tracking to user-experience-related research was studied (Fitts et al. 1950). The advancement of technology since then has allowed for greater accuracy and precision, while making data analyses simpler and less obtrusive on users and researchers alike. Eye-tracking has been used in numerous studies related to marketing (Djamasbi et al. 2010), education (Mayer 2010), user experience (Granka et al. 2004), and disease detection (Zola et al. 2013).

Modern commercial eye-trackers use infrared light to create a reflection in the eye, while a camera is focused on the eye and records the reflection. Advanced image processing algorithms calculate the location of the observer's point of gaze related to the eye and the stimuli (Galesic et al. 2008; Bojko 2013; Bergstrom 2014). The attributes that allow accurate representation and understanding of an individual's eye movement behavior are location-detection of the location of a user's gaze relative to a point in time (fixation), duration (the length of time that a user fixates at a particular visual element), and movement (movement of a user's eyes based on saccades from one fixation to another) (Bergstrom 2014). Location, duration, and movement are used to establish the eye-gaze pattern that reflects how the user interprets a particular visual stimulus, which provides the foundation for understanding the visual hierarchy of a scene (Djamasbi et al. 2010; Bergstrom 2014). Visual hierarchy refers to the arrangement of elements in ways that influence the order of importance the human eye perceives and dictates an individual's attention and duration (Wade and Sommer 2006; Jackson 2008; Djamasbi et al. 2010; Bergstrom 2014).

2.5.1 Image Viewing Physiology

Understanding the physiology of the eye, and the ways in which images are viewed and processed, can allow for better comprehension of eye-tracking principles. Eye movements can be divided into two categories: fixations and saccades (Buscher et al. 2009; Dorr et al. 2010; Bergstrom 2014). A fixation is the pause of an eye movement (lasting between one-tenth and one-half of a second), during which the eye gazes at a specific location of the visual field (Buscher et al. 2009; Bojko 2013). A saccade is the rapid eye movement from one fixation to the next. Vision, for the most part, is suppressed during saccades to prevent blurring of the visual field. Visual information is only extracted during fixations, when the eyes are relatively motionless and are focusing on stimuli (Buscher et al. 2009; Bojko 2013). The visual field for humans consists of the foveal, para-foveal, and peripheral vision (Bojko 2013; Bergstrom 2014). Fixations occur in the foveal vision, which accounts for only 1-2° of the visual field. Foveal vision is the part of vision that is highly detailed and provides the register for primary attention.

(Bergstrom 2014). Saccadic eye movements, consisting of saccades and fixations, are of the greatest interest to user-experience research (Bojko 2013).

Concerning image viewing behavior, there are three main factors that influence the location of fixations: 1) salience of areas within the image; 2) memory and expectations of where to find information; and 3) the desired task and information need (Buscher et al. 2009). The salience of areas is based on image characteristics that include contrast, color, intensity, edge density, and edge orientation. The first fixation is located on the most salient spot, with the subsequent fixations being placed in order to maximize information gain. Memory and expectations also play key roles in subsequent fixations. Research suggests that concepts are more likely to be remembered through the use of images than text alone (Nelson et al. 1976; McBride and Dosher 2002; Whitehouse et al. 2006; Ally et al. 2009; Curran and Doyle 2011; Krum 2013; Medina 2014). The imagery must be relevant to the content, which will reinforce the desired message or theme from the data. According to the Picture Superiority Effect, memory retention is amplified over time when relevant imagery is used. Graphic designers use the Picture Superiority Effect in advertisements, presentation slides, posters, brochures, websites, billboards, and infographics to increase recognition and working memory (Krum 2013; Medina 2014).

2.5.2 Conclusion

Eye-tracking offers the ability to identify elements that attract the user’s primary attention. This information can be used to ensure graphical effectiveness that will support learning and communication success rather than impede it. Working with unique populations, such as low literacy and diverse ethno-linguistic groups, can be difficult due to language and cultural barriers. Eye-tracking can be used as an investigative tool in the design process of educational materials for these types of individuals, especially during the creation of complex information (Goldberg and Helfman 2010; Bergstrom 2014). The design of informational materials to accommodate unique populations can be enhanced through the use of eye-tracking methods by determining which elements attract attention and increase usability and understanding. No known studies have attempted to use eye-tracking devices for education research in rural, low literacy communities**.** Eye-tracking is traditionally conducted in controlled laboratory settings with stationary eye-tracking technology. Laboratory-based investigations, however, limit the use of eye-tracking in education studies specific to a hard-to-reach target population, despite the importance of including input from these populations in the design of educational materials.

2.6 Summary

Currently, more than 1 billion people obtain their drinking water from contaminated sources (WHO/UNICEF 2006; Clasen et al. 2008). This number could grow even larger, as Africa has a projected increase of 1.3 billion people between now and 2050. Most, if not all, of the growth will occur in sub-Saharan Africa. The lack of proper sanitation, hygiene, and clean water in sub-Saharan Africa fosters environments where water-borne pathogens and communicable diseases cause high mortality rates (Montgomery and Elimelech 2007; Mäusezahl et al. 2009). Widespread poverty will continue to constrain each country's ability to address its current and future water issues. Health interventions can lead to positive outcomes among target populations in water-education campaigns; however, low-literacy, cultural, and socioeconomic barriers are restricting the implementation and success of interventions among vulnerable populations in sub-Saharan African countries. Alternative methods, such as the use of visual communication, could be used to overcome the barriers of mother tongue and low literacy (Curran and Doyle 2011; Krum 2013). Visual learning design, specifically incorporating graphic design to foster visual storytelling, could provide a new approach to water education for target populations. The effectiveness of visual communication can be quantified using eye-tracking technology, which allows researchers the ability to comprehend the complete and complex user experience, even that which users cannot describe or explain (Bergstrom 2014). Effective graphics are fundamental for understanding intricate information and completing tasks that are difficult to learn. Culturally relevant graphics that attract attention can foster working memory and recall, thus leading to an environment that supports, rather than impedes, learning (Curran and Doyle 2011). Eye-tracking methods can be used to measure graphical effectiveness and provide a better understanding of how health interventions promote learning: i.e., observers are not distracted by design elements and focus on key constructs and concepts leading to improved design and ultimately graphical effectiveness. Overcoming the desperate need for improved water educational materials can help reduce the cycle of sickness and death within sub-Saharan Africa (George 2009; Bizzarri et al. 2011).

Chapter 3: Study Area and Cultural Context

3.1 Geography and Climate

Niger is a landlocked country of West Africa positioned primarily in the Saharan Desert (Afifi 2011; Yayé et al. 2013). The country covers an area of 1,267,000 km^2 with a total population of nearly 16 million people (World Bank 2014c) and shares borders with Algeria and Libya to the north, Nigeria and Benin to the south, Chad to the east, and Burkina Faso and Mali to the west (Figure 3.1). The capital city of Niamey lies in the southwestern part of the country on the banks of the Niger River. Lake Chad was once found in the southeast region of the country and was shared with Nigeria and Chad; however, the lake has dried out within Niger's borders (Grote and Warner 2010). Although Niger is the largest country in West Africa and the fourth largest in all of Africa (Grote and Warner 2010), most of its territory is uninhabited (Afifi 2011).

The Saharan Desert covers three-fourths of Niger (Yayé et al. 2013); starting from the north and working to the south, the arid desert changes to semi-arid savannah and eventually to a narrow tropical zone (Mohamed et al. 2002). Niger is approximately 80% arid and 20% semi-arid (Peel et al. 2007), with maximum temperatures reaching 45°C from April to May (Yayé et al. 2013; Laya 2014). For comparison, Niger (1,267,000 km^2) is slightly larger than the "Four Corners" states of Colorado, Arizona, Utah, and New Mexico (1.10 million km^2). The Köppen Classification Scheme (Figure 3.2) is similar to Northern Mexico, West Texas, the Desert Southwest, and Northern New Mexico (Peel et al. 2007). Of Niger's total land area, only 25% (316,750 km^2) is suitable for cultivation, and only 150,000 km^2 is usable for agriculture (Mohamed et al. 2002). The southern part of the country is located in the Sahel climate zone, which is characterized by a single rainy season (Laya 2014). The rains last for only three months, with total rainfall ranging from 150 - 600 millimeters per year (Yayé et al. 2013).

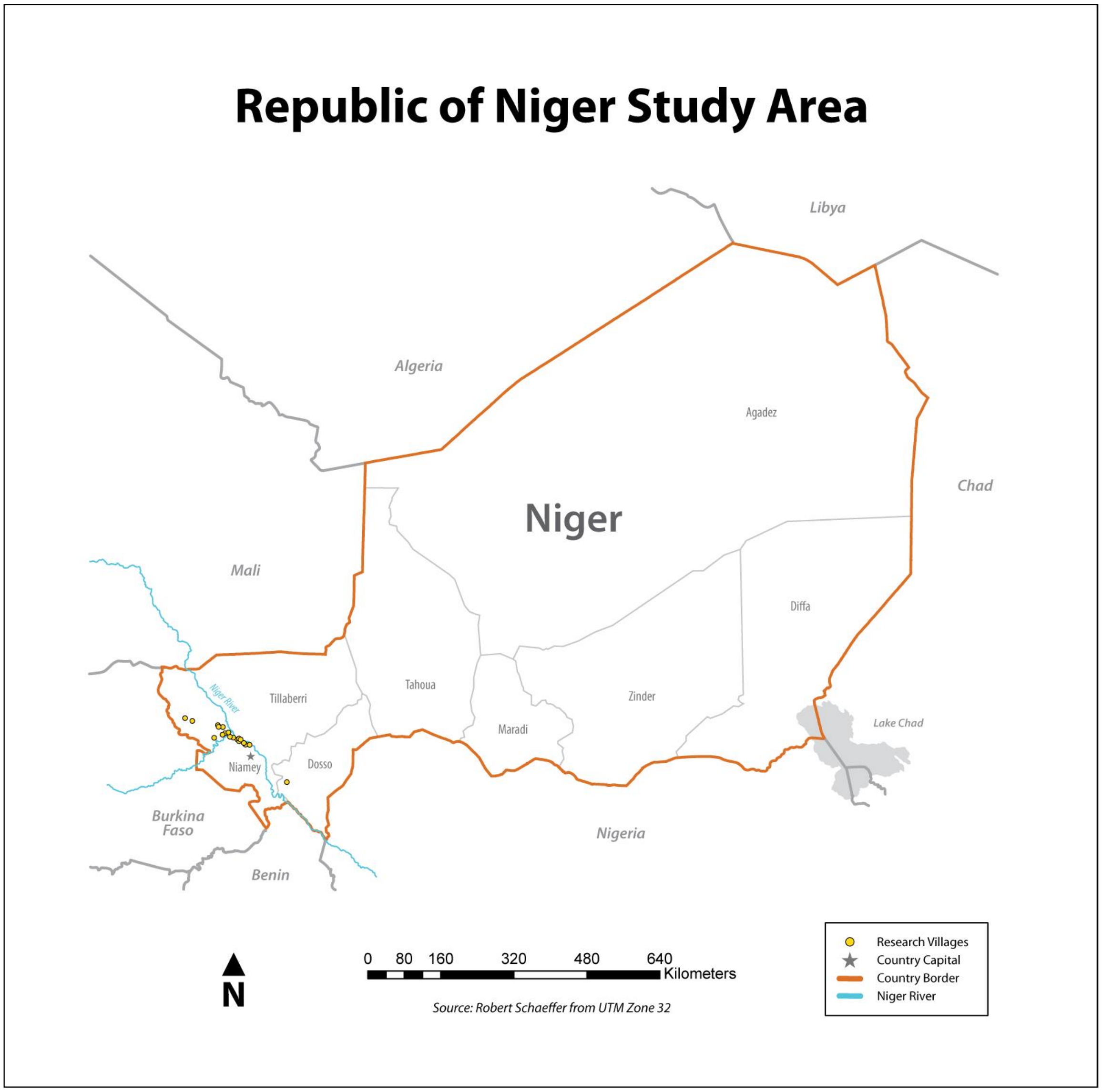

Figure 1. Republic of Niger Study Area.
Source: Adapted by the author.

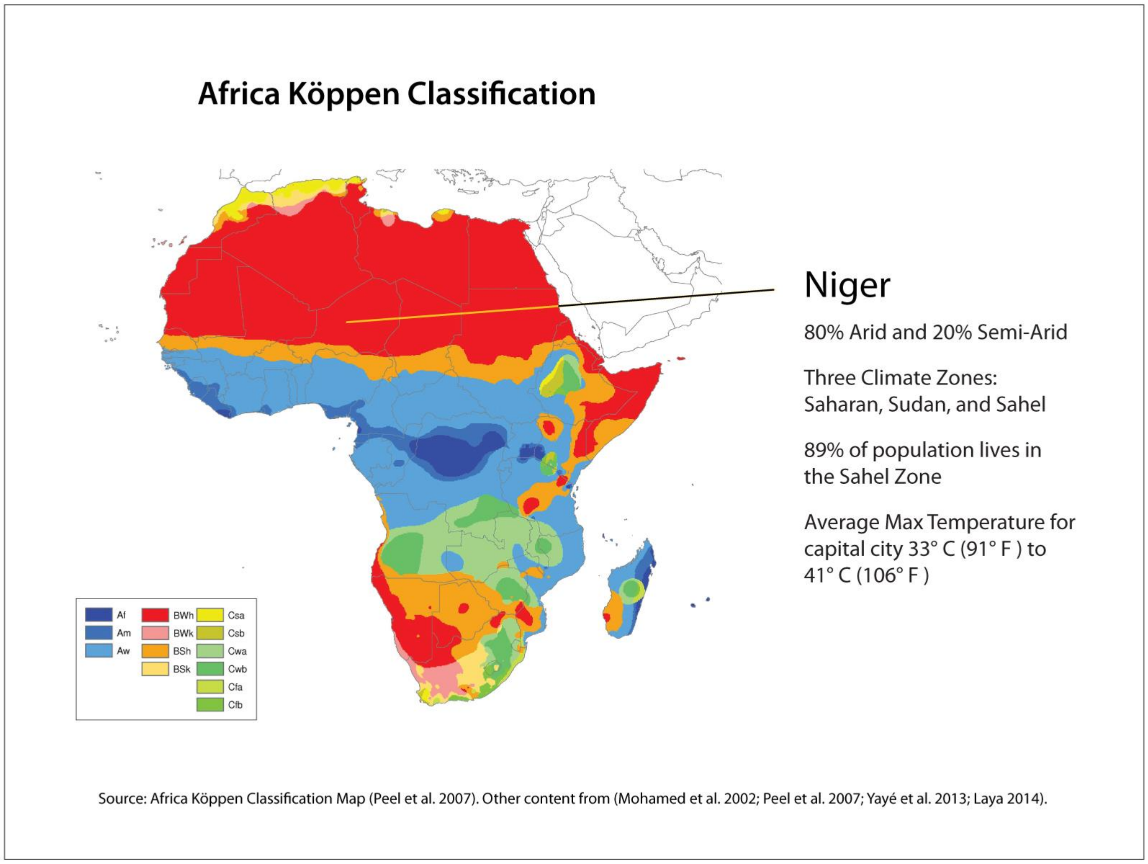

Figure 2. Africa Köppen Classification.
Sources: Peel et al. 2007; Mohamed et al. 2002; Yayé et al. 2013; Laya 2014.

3.2 Population

The country of Niger consists of eight administrative regions: Agadez, Diffa, Dosso, Maradi, Niamey (the capital of Niger), Tahoua, Tillaberi, and Zinder. The population is concentrated along the southern part of the country (Yayé et al. 2013) in the regions of Maradi and Dosso that correspond with the increasing aridity from south to north (Grote and Warner 2010). Unequal population distribution imposes pressure on the arable land in the southwestern part of the country, with 100 inhabitants per square kilometer compared to the national average of eight inhabitants per square kilometer (Yayé et al. 2013). There are approximately 10,000 villages throughout the country, of which half have only a few hundred inhabitants (Fuglestad 2014). In 2010, the population of Niger totaled 15,893,746 million people, of which 13,102,963 million (82.4%) lived in rural areas (World Bank 2014c). Niger has the world's highest total fertility rate at 7.4 births per person, which drives the world's fastest growing population with an estimated growth of 58 million by 2050 (Potts et al. 2011). Several different cultural groups are divided into settled populations throughout the country: in the southwest, the Songhai; the Hausa in the country's center; the Kanuri in the east; and the nomadic populations of the Tuareg and Fulani live to the country's north (Grote and Warner 2010; Laya 2014).

3.3 Ethnic and Linguistic Groups

Niger's official language is French; however, it remains understood only by a small minority (Laya 2014). In addition to French, there are five main linguistic groups that correspond to five main ethnic groups (Fugelstad 2014). These ethno-linguistic groups can be divided further into sub groups and dialects. The main ethnic groups include Hausa, Songhai, Fulani, Kunari, and Tuareg. Ethnic groups can be found dispersed geographically in country specific regions among sub group populations (Fugelstad 2014). The major language groups in Niger include: Hausa, spoken by the Hausa people; Songhai, spoken by the Songhai people and divided into various dialects, such as Songhai proper, Zerma, and Dendi; Fula, spoken by the Fulani and divided into eastern and western dialects; Tamachek, spoken by the Taureg; and Kanuri, also called Beriberi, spoken by the Kanuri. In addition, many of the people of Niger speak, read, and write Arabic, which has historical relevance, as the region of Agadez possesses one of the oldest Arabic schools in Africa (Laya 2014).

3.4 Socioeconomics

Economically, Niger is one of the poorest countries in the world (UNDP 2014), with nearly half of the country's budget derived from foreign donors (Afifi 2011). People in Niger rely heavily on the environment on a daily basis; 90% of the labor force actively engaged in subsistence farming, livestock, and fishing (Afifi 2011). Millet is the most important agricultural crop, occupying nearly half of the total harvested area in the country (Yayé et al. 2013). Niger has some of the world's largest uranium deposits in the northern part of the country, yet access is limited due to location (Afifi 2011). According to the Human Development Index (HDI), Niger ranks last out of 178 countries. The HDI is a measure used to assess long-term development for countries, and the United Nations recognizes territories in three dimensions: 1) a long and healthy life, measured in life expectancy; 2) access to knowledge, measured by mean years of education; and 3) standard of living, measured by Gross National Income per capita expressed in international dollars converted using purchasing power parity rates (UNDP 2014). Niger is characteristic of a life expectancy of 58 years, 1.44 mean years of schooling, and with 89.8% of the population living in multi-dimensional poverty (UNDP 2014). Insufficient education levels in Niger are best illustrated by the adult literacy rate at 15% (UNESCO 2012) and a female literacy rate of 9% (Grote and Warner 2010).

3.5 Gender Inequality

Although education in Niger is free, only a small percentage of children attend school (Fugelstad 2014). Poverty and limited access to schools within the Sahel region of Niger create challenges for learning (Fugelstad 2014; Thomas 2014). The Sahel region, where most of Niger's population is concentrated, is considered to be one of the harshest places to live in the world, particularly for women and children (Yayé et al. 2013; Thomas 2014). Water fetching is mainly gender-specific, with girls alone spending up to four hours per day carrying water from sources to their homes (Thomas 2014). The burden of water collection makes it difficult for girls to attend school and limits their other educational opportunities. Niger has the lowest Gender Development Index value in the world at 0.729 for females, the lowest female Human Development Index at 0.287, and the lowest mean years for females schooling at 0.8 years (UNDP 2014). The Gender Development Index measures differences between male and female achievements of human development in three dimensions: 1) health, measured by female and male life expectancy at birth; 2) education, measured by female and male expected years of schooling for children and female and male mean years of schooling for adults ages 25 and older; and 3) equitable command over economic resources, measured by female and male estimated earned income (UNDP 2014). In Niger, the percent of women aged 25 and older with at least some secondary education is only 2.4%, compared to that of males with 7.8% (UNDP 2015). With a Gender Inequality Index of 0.713, Niger is ranked 154th out of 155 countries. The Gender Inequality Index expresses the loss in potential human development due to disparity between female and male achievements in dimensions of empowerment and economic status and reflects a country's position for women's health (UNDP 2015). In Niger, 75% of girls are married before they are 18, which can further confine their ability to attend secondary school (Winthrop and McGivney 2014).

3.6 Water Supply Deficiencies and Implications

The lack of dependable water supplies and sanitation in Niger has led to an environment that fosters disease and malnutrition (Figure 3). Each day in Niger, 33 children (12,000 per year) die from diarrhea caused by unsafe drinking water and improper sanitation (Wateraid 2014), while 40% of children suffer from malnutrition and growth deficiency (Afifi 2011). More than 90% (14 million people) of the population does not have access to proper sanitation, and nearly 50% (8 million people) do not have access to safe drinking water (Wateraid 2014; World Bank 2014a; 2014b). In addition, 81% of the population practices open defecation (Galan et al. 2013).

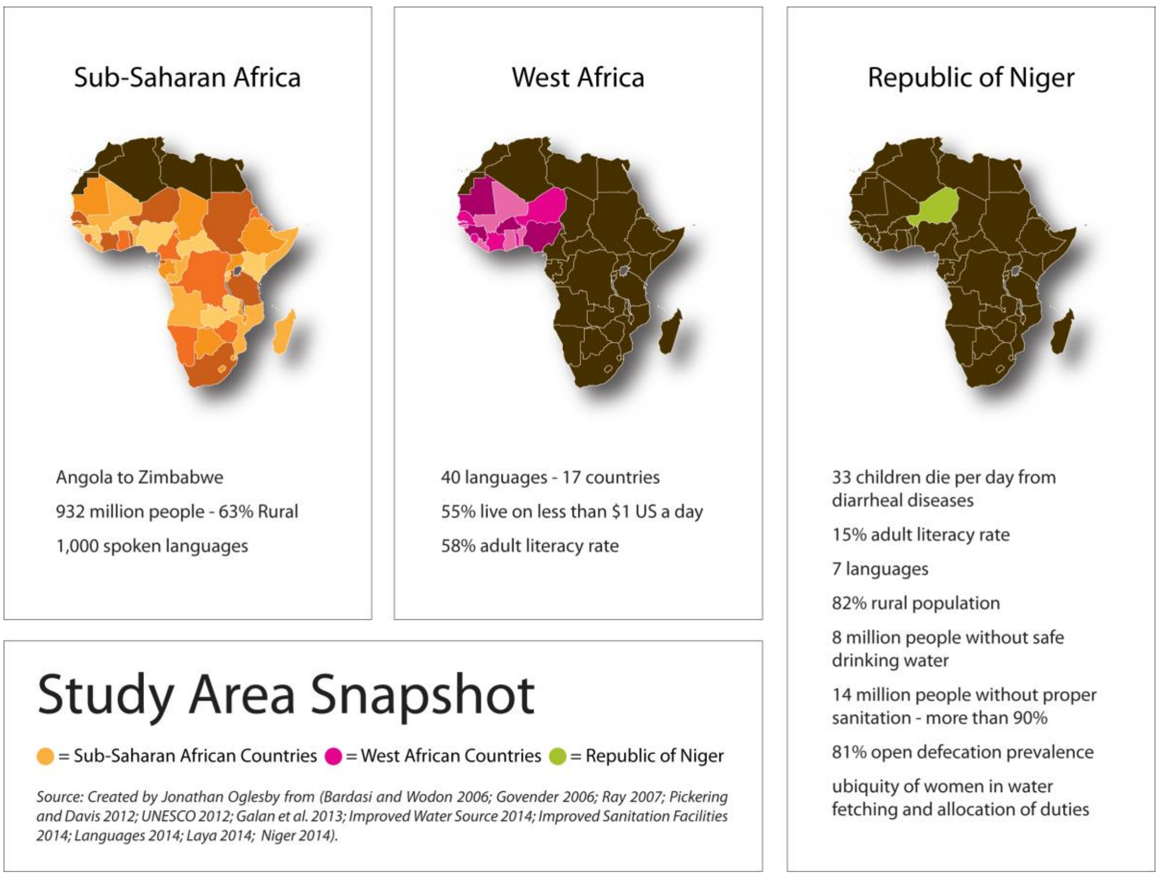

Figure 3. Sub-Saharan Africa to Niger statistical breakdown.
Sources: Created by author from Bardasi and Wodon 2006; Govender 2006; Ray 2007; Pickering and Davis 2012; UNESCO 2012; Galan et al. 2013; Laya 2014; WAG 2014; Wateraid 2014; World Bank 2014a; 2014b.

3.7 Conclusion

The Republic of Niger was chosen as the study area for this research due to its water supply deficiencies and challenges, multiple ethno-linguistic groups, low literacy levels, and its large rural population. In addition, the physical geography and climate of Niger, coupled with the socioeconomic status of its inhabitants, create a diverse and dynamic environment full of challenges that provide opportunities for in-depth research about water literacy communication. As Niger is home to the world's fastest growing population, with an estimated growth of 58 million by 2050 (Potts et al. 2011), its current problems will increase in magnitude and complexity if changes are not implemented both now and in the future. Overcoming the desperate need for improved water educational materials can help break the cycle of sickness and death within Niger.

Related to the selection of Niger as the case study site, the context of culture and place offered a unique opportunity for the methods used in this research, as well as the possible data that could be collected. Niger is over 80% rural, with over 10,000 villages. Limited water resources, due in large part to the physical geography of Niger, dictate that 90% of water for personal use is collected from the Niger River. Water duties are predominately gender-specific in Niger; therefore, women were targeted as the study population while they conducted their daily duties in and around water sources. Deep-rooted village dynamics and cultural roles were addressed by the subjective cognizance of translators and interpreters: i.e., seeking permission from village chiefs, male elders, and/or village health care workers before beginning research, speaking to women after permission was gained, and being respectful of cultural customs and traditions. Eye-tracking was performed in non-traditional laboratory village environments, as the research had to be conducted within certain limitations, such as distractions, lack of electricity, and the use of abstract concepts, along with the uniqueness of places to perform such testing (mud brick homes, medicinal depositories, and maternity wards). By performing this case study in Niger, educationally effective WSH materials could be developed in a place in dire need of such materials. Unique methods could be developed and tested by including women and diverse cultural groups.

Chapter 4: Methods

For this research, visual learning design factors were incorporated into water literacy materials in rural West Africa in order to study ways in which cultural and societal barriers can be overcome through culture- and gender-appropriate graphic design to foster visual storytelling. Research was conducted in 23 villages along the Niger River in the Republic of Niger, which included 510 interviews, 693 focus group participants, and 464 eye-tracking trials. Institutional Human Subjects Review Board approval was acquired in February 2014. Children were not used in this research. Nine different cultures were included in this study: Songhai, Zerma, Hausa, Kutay, Gourmanche, Fulani, Kado, Mori, and Tamachek. Eye-tracking technology and Geographic Information System (GIS) tools were used to quantify and support a design approach for the evaluation of water education materials in underrepresented groups. Women were targeted as the study population, as they are the primary water fetchers and handlers in sub-Saharan Africa. Kernel density estimation (KDE) analyses were performed in an effort to compare and contrast varying education levels, age groups, and village types. Spatial autocorrelation analyses for the Solar Disinfection visualization were used to evaluate whether the spatial pattern of attribute values (fixation time) was clustered, dispersed, or random. Figure 4 provides an overview of the steps taken for this research. These methods were used in the attempt to: 1) reveal the attention path and fixations of observers of presumably informative water materials, 2) evaluate the effectiveness of each instructional visualization through pre and post outcomes assessments and semi-structured interviews, and 3) determine the characteristics of effective instructional tools and discern how and why these characteristics have an impact on the understanding of water pollution, water purification, and sanitation and hygiene.

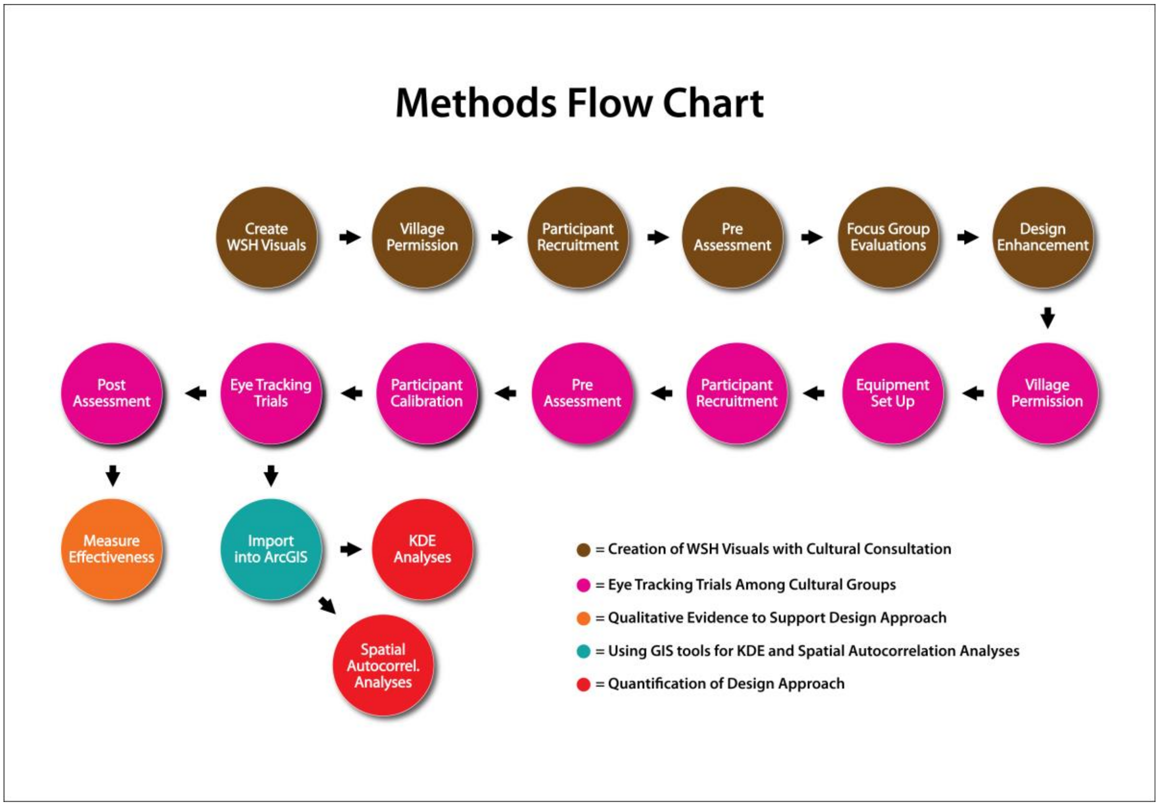

Figure 4. Methods Flow Chart. Source: Created by author.

4.1 Graphical Design of Interventions

Education materials were created using visual learning design techniques that entailed key WSH concepts. Visual learning design was used in the creation of materials, as the research had to consider mother tongue and literacy, which are constraints that are commonly not mentioned or considered nearly enough in WSH intervention approaches. Visualizations were designed considering four processes noted by Mansoor and Dowse (2004): 1) connect with existing knowledge from the target population, 2) attract the attention of the target population, 3) hold the population’s interest, and 4) present the data and information in ways that lead to population adherence. Visual communication in the form of illustrations that incorporate visual storytelling techniques (Duarte 2008) comparable to pictograms were used, since pictograms have been shown to enhance comprehensions and recall of information when used appropriately (Cowgill et al. 2003; Yin et al. 2008). The design of the visuals took into consideration cultural sensitivities, minimized distracting details, and incorporated illustrations that supported key points relevant to the cultural people (Carstens 2004). Objects, symbols, clothing, landscapes, people, and environments familiar to the target populations were used. Visual storytelling techniques, emotional story structure techniques (Duarte 2013), and visual thinking processes (Ware 2008) that utilized cultural- and gender-appropriate images were integrated together to create the visuals (Morris and Stillwell 2003; Carstens 2004). All graphical design heuristics offered by Carstens (2004) were used (see literature review) in the creation of education materials.

Themes for interventions were categorized into water, sanitation, and hygiene. The following WSH interventions were selected for evaluation in this project: 1) water interventions using the point-of-use treatment techniques of boiling (Sobsey 2002; Sodha et al. 2011) and solar disinfection (Kehoe et al. 2001; Dejung et al. 2007; Agrawal and Bhalwar 2009), 2) sanitation intervention with the use of pit latrines for the promotion of open defecation free areas and non-point source pollution (George 2009; Mara et al. 2010), and 3) hand washing with soap (Lowbury et al. 1964; Ansari et al. 1989; Curtis et al. 2009). Social, physical, and biological aspects were considered when decisions were made on which specific intervention would best serve the target population (Fewtrell et al. 2005; Curtis et al. 2009). In addition, subjective cognizance and observations by the author from repeat visits over an 8-year time period determined limited resources and affordability available to the cultural groups studied.

4.1.1 Target Population Consultation

Visualizations (see Figures 6, 7, 8, and 9) were evaluated among low-literacy cultural groups in West Africa in order to provide feedback and the consultative factor necessary for proper design and effectiveness (Mansoor and Dowse 2004; Curtis et al. 2005). Interview and survey questions were semi-structured and stemmed from the main themes determined for the interventions. Research-based design heuristics provided guidelines for designing the content, structure, and style of survey questions and interviews (Morris and Stillwell 2003; Carstens 2004).

4.1.2 Data Collection

Professional translators, who had worked in previous areas and had developed working relationships with village chiefs and health care workers, chose villages for data collection. By allowing national partners and hired professionals the task of choosing villages, researcher bias was limited and data collection success was fostered. Although women were recruited for focus groups sessions, male village elders and other village men did participate in the sessions; their data were not included in the results of this study. Before working in the villages, permission was sought from the village chief to conduct research. Women of varying ages and education levels were recruited to participate through a convenient sampling strategy by walking around the villages where they congregated (river, wells, home compounds) and starting conversations as women performed daily tasks. Semi-structured interviews and surveys were conducted in rural villages in the Republic of Niger in March, 2014. Fifteen villages along the Niger River served as study areas for data collection. The villages had a mix of populations, ranging from 200 to 15,000 residents. The villages included markets, farming, and fishing communities (Table 1). Forty-six focus-group sessions that included 693 participants were documented during this phase of the research project. Over six hours of audio interviews were recorded.

Village Information for Focus Groups Evaluations

Village Name	Population	Village Type	Participants
Bangou Koira Zeno	6000	Market / Fishing / Farming	75
Boubon	17000	Market / Fishing / Farming	23
Ganguel	200	Fishing / Farming	30
Garbey Kourou	7000	Market / Farming	171
Kakassi	1000	Farming	47
Koseye	200	Fishing / Farming	10
Kwarey Gourou	500	Farming	1
Latta	1500	Farming	33
Larba Birni	15000	Market / Farming	206
Namarou	12500	Market / Fishing / Farming	3
Sarando	2000	Farming	16
Settore	750	FIshing / Farming	30
Siloe	1000	Farming	25
Yonkoto	1500	Fishing / Farming	10
Yorizey Koira	1500	Farming	13

Village populations are estimates derived from health officials and interpreters cognizant of geographic locations.

Table 4.1. Village information for focus groups evaluations.

Participants were asked survey and interview questions designed to solicit opinions about the education materials in their mother tongue, which enabled individuals to participate more and created an environment that integrated the culture (Alidou et al. 2006). This was achieved through the use of professional translators who are fluent in cultural target group languages and customs. All responses were digitally recorded and later transcribed. Pre-knowledge of water education material topics were assessed through pre-survey and interviews. Education materials were printed on laminated card stock and displayed in front of the participants on the ground (Figure 5).

Figure 5. Displaying visualizations for focus-group participants.
Source: Photo courtesy of Mark Phillips.

It is customary for the visitor to the village or village home to be treated with respect and given a chair to sit in or sit on the ground with a cloth laid out as people gather around and listen. Interviews were conducted through the aid of a translator and recorded to ascertain post-knowledge and solicit opinions about the education materials. For the focus group sessions, visualizations were displayed in front of the participants, followed by the respective interview questions pertaining to that intervention.

Visualization interview and survey questions used in this phase of the research project, and the order in which they occurred, are listed below:

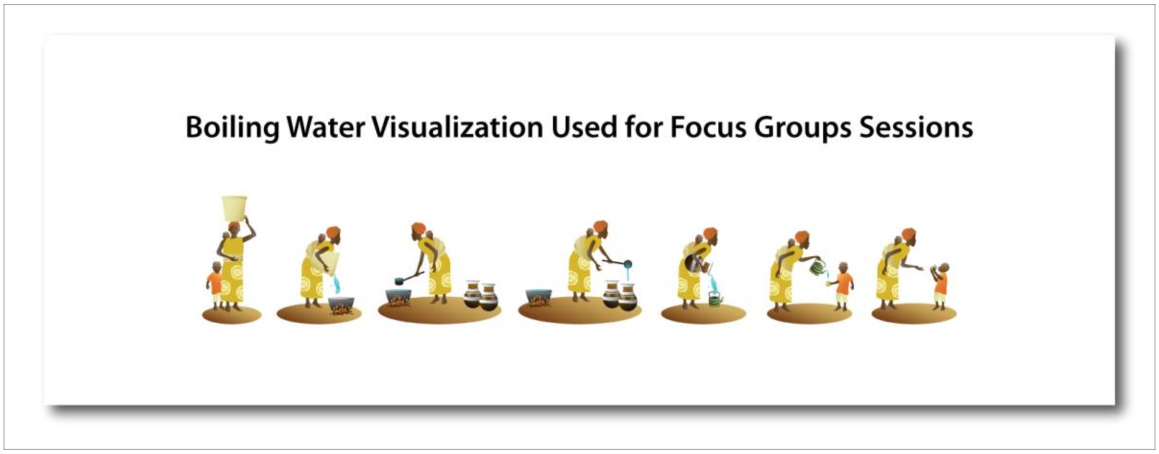

Figure 6. Boiling water visualization used for focus group sessions.
Source: Created by author.

Boiling Water

1. Can you explain the story?
2. What did the woman do with the water she fetched?
3. Do you think it's important to do what she did?
   Why or Why not?

Boiling Water and Drinking

1. How did the story change?
2. What is the boy doing?
3. What made the water safe to drink?

What did you like & not like?
What would you change?
What would make it better?

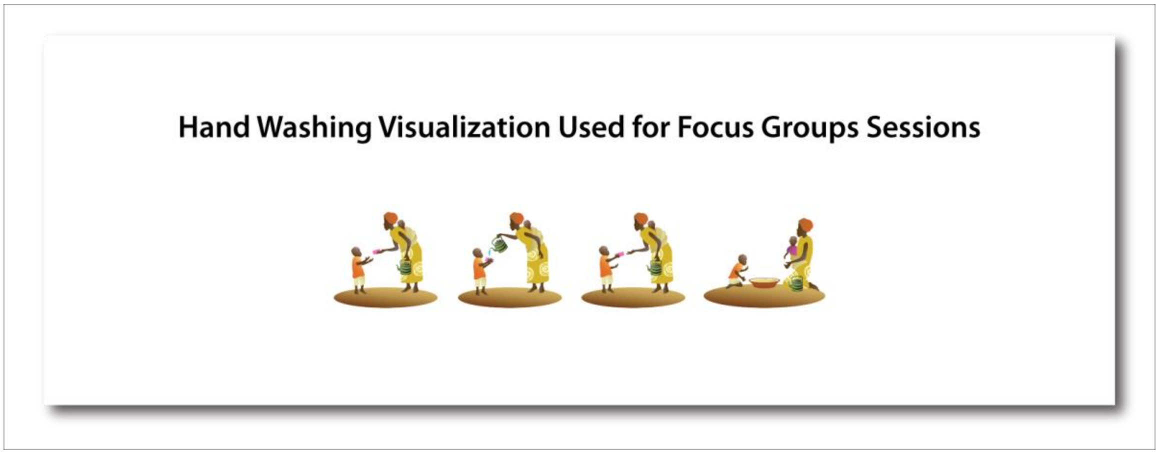

Figure 7. Hand washing visualization used for focus group sessions.
Source: Created by author.

Hand Washing

1. Can you explain the story?
2. What is the boy doing?
2. Do you think it’s important to do what the boy did?
   Why or Why not?
3. Do you wash your hands? Will you wash your hands?

Hand Washing and Eating

1. How did the story change?
2. What is the family doing?
3. Did they do anything before they ate?

What did you like & not like?
What would you change?
What would make it better?

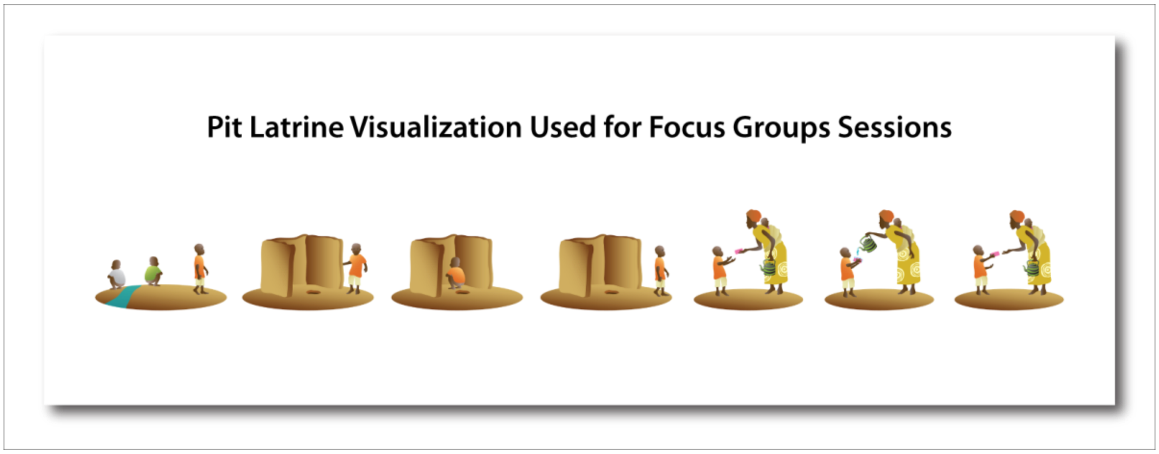

Figure 8. Pit latrine visualization used for focus group sessions.
Source: Created by author.

Pit Latrine

1. Can you explain the story?
2. Did you notice the boy went to the pit latrine & not the river?
3. Why did he do this?
3. Do you think it's important to do what he did? Why or Why not?

Pit Latrine and Hand Washing

1. How did the story change?
2. What is the boy doing?
2. Do you think it's important to do what the boy did?
   Why or Why not?
3. Do you wash your hands? Will you wash your hands?

What did you like & not like?
What would you change?
What would make it better?

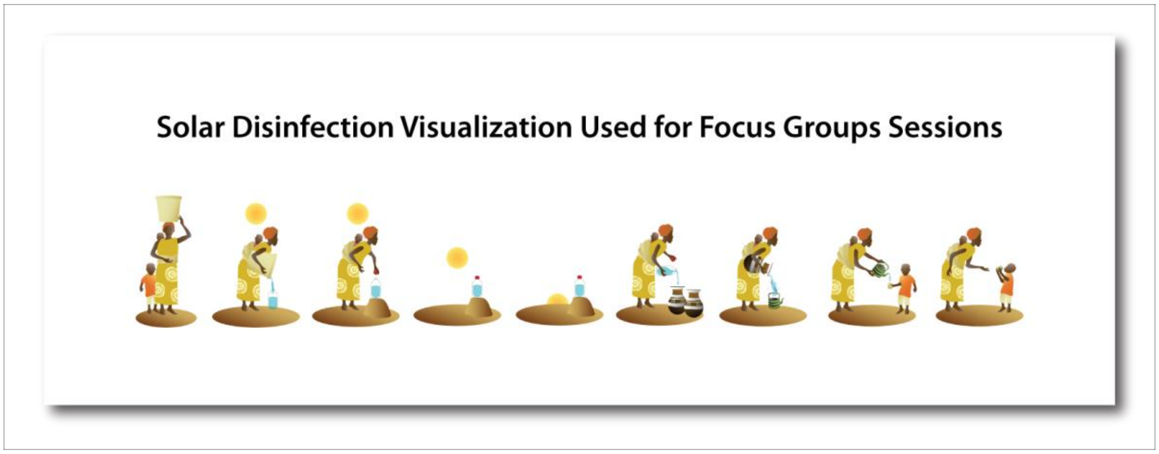

Figure 9. Solar disinfection visualization used for focus group sessions.
Source: Created by author.

Solar Disinfection

1. Can you explain the story?
2. Did you notice the mother waited before she poured out the water?
3. How long did she wait?
4. What does this do to make the water safe to drink?

Solar Disinfection and Drinking

1. How did the story change?
2. What is the boy doing?
3. What made the water safe to drink?

What did you like & not like?
What would you change?
What would make it better?

4.1.3 Focus Group's Visual Learning Effectiveness

Post semi-structured interviews were transcribed using descriptive and analytic coding techniques (Clifford et al. 2012). Focus groups assessments, in the form of semi-structured interviews, were designed with pertinent questions in order to quantify the graphical effectiveness of each intervention by measuring correct answers for core constructs. Two categories were used to code the transcribed interviews: what is occurring in the education material and why it is important (e.g., hand washing with soap before eating reduces the transmission of pathogens, viruses, and bacteria). Semi-structured interviews were transcribed and content was assessed using a scoring rubric (Andrade 2005; Jonsson and Svingby 2007; Reddy and Andrade 2010) for correct and incorrect answers. Participant responses were scored 0 for an incorrect answer and 1 for a correct answer. Each question score was summed for each assessment in order to determine the visual learning effectiveness for each intervention (see Table 2). In addition, the intervention visualizations (Figures 6-9) were evaluated to provide feedback and the consultative factor necessary for proper design and effectiveness (Mansoor and Dowse 2004; Curtis et al. 2005). Research-based design heuristics provided guidelines for designing the content, structure, and style of survey questions and interviews (Morris and Stillwell 2003; Carstens 2004).

Focus Groups Visual Learning Effectiveness

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
VLE	693	1.20 (60%)	1.48 (74%)	1.72 (86%)	0.47 (24%)

VLE = Visual Learning Effectiveness Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.
Source: Data created by author from eye-tracking trials.

Table 2. Focus groups visual learning effectiveness.

4.2 Eye-Tracking

Transcribed responses to the participant audio interviews and surveys from the focus group sessions were used for design enhancement of educational materials in order to improve effectiveness. Newly designed visualizations (see Figures 12-15) were evaluated in July, 2014, among low literacy cultural groups in West Africa in order to measure the effectiveness of the learning design approach incorporated by using eye-tracking verification analysis. Twelve rural villages in the Republic of Niger served as study areas, where 464 eye-tracking trials were conducted and nearly 24 hours of audio interviews were recorded. Permission was sought from the village chief to conduct research; in the case of working at health clinics, permission was sought from the clinic major (head doctor, nurse, or caregiver). Women were once again recruited to participate through a convenient sampling strategy, by using ethnic males who walked around the villages where women congregate (river, wells, home compounds) and started conversations as they performed their daily tasks. Using ethnic males in the recruitment process of women provided crowd control and validity for the research, as it is culturally respectful for women to listen to male elders in the village hierarchal system. Village information for eye-tracking trials can be found in Table 3.

Pilot testing was performed in the capital city and several villages using ethnic males to ensure tasks and stimuli elicit the participant behaviors that address the study objectives. In addition, pilot testing allowed for the refinement of translated instructions and task order (Bojko 2013). Eye-tracking trials were conducted in bush maternity wards, medicinal depositories, and mud-brick homes, as traditionally controlled laboratory environments were not feasible for this study. Target populations live and work in rural, low literacy villages; therefore, commonly observed laboratory eye-tracking settings and practices were conducted in the best attempt to capture people's natural behavior and limit any possible interferences such as lighting and distractions (Bojko 2013; Bergstrom 2014). Figure 10 offers an overview of the methods used for the eye-tracking trials.

Village Information for Eye-Tracking Trials

Village Name	Population	Village Type
Bassi	1900	Fishing / Farming
Bangou Koira Zeno	6000	Market / Fishing / Farming
Boubon	17000	Market / Fishing / Farming
Doumba	1000	Farming
Gounday	2000	Market / Farming
Hondey Tegui	1800	Farming
Kakassi	1000	Farming
Kouli Koira	12500	Market / Farming
Latta	1500	Farming
Namarou	12500	Market / Fishing / Farming
Tagabatti	1900	Farming
Toure	150	Farming

Village populations are estimates derived from health officials and interpreters cognizant of geographic locations.

Table 3. Village information for eye-tracking trials.

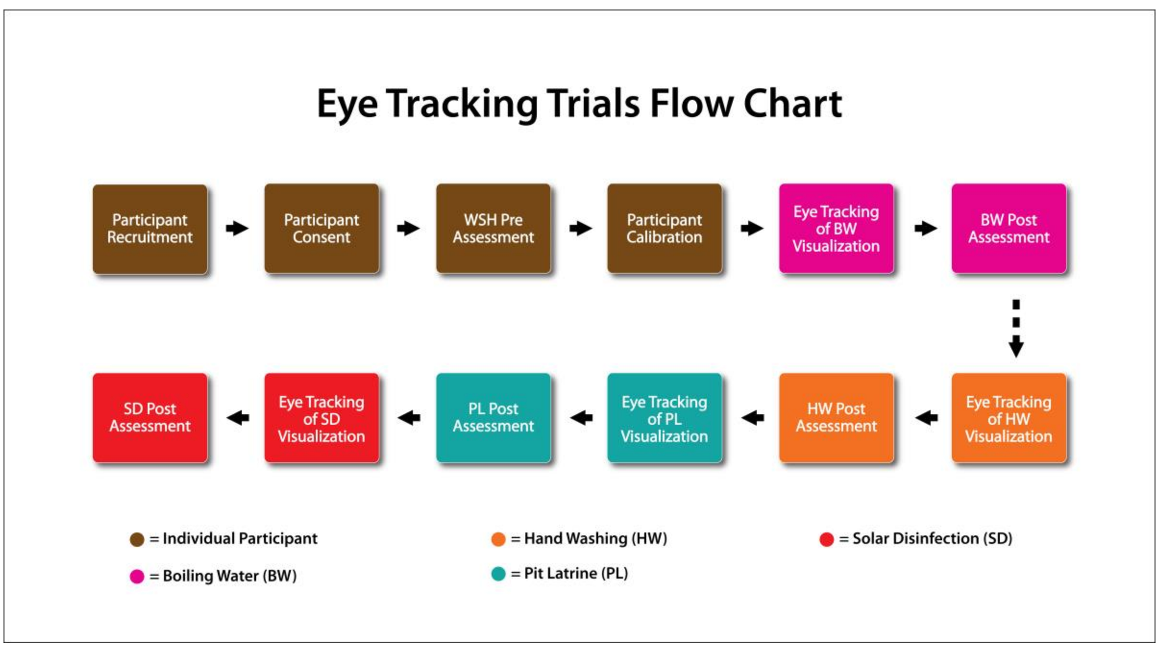

Figure 10. Eye Tracking Trials Flow Chart.
Source: Created by author.

4.2.1 Eye-Tracking Equipment

Eye-tracking in rural West African villages is novel in design approach and scope. Technological limitations of eye-tracking include lighting, distractions, calibration variables, and eye-tracking concepts that are abstract to target populations. These limitations were alleviated by the use of professional translators and interpreters who were trained in research goals and methods. In addition, indigenous people were used throughout the entire study. Field pilot testing was incorporated to determine potential problems before eye-tracking began (Bojko 2013; Bergstrom 2014).

Due to the nature of the study being conducted in rural village environments, portable eye-tracking equipment and accessories were utilized. Specifically, a laptop computer with a Tobii X2-60 Eye Tracker attached was used for this research. This eye-tracking device was chosen for its versatility, which can attach magnetically to any laptop, and its data point collection speed of $1/60^{th}$ of a second. A 400-watt, 12-volt, 3.48 amps power inverter directly connected to a truck battery provided power to the eye-tracker and laptop computer. The power inverter was used to convert a vehicle's DC power to 115 volts AC power. In addition, three folding chairs and a folding table were carried to each village and used in the eye-tracking trials (Figure 11).

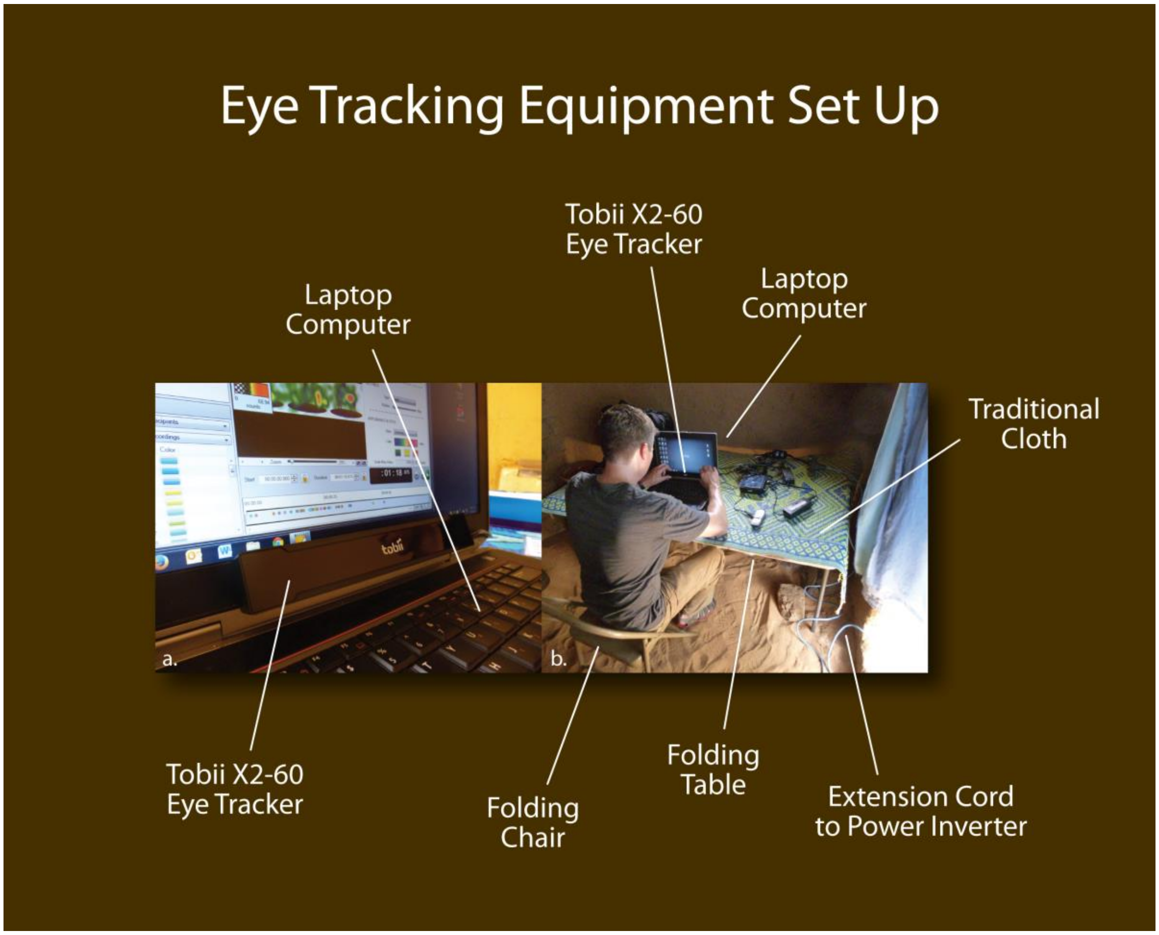

Figure 11. Eye tracking equipment set up.
Source: Photos courtesy of Mark Phillips.

4.2.2 Eye-Tracking Pre-Assessment

After village and/or health clinic permission was gained, recruited individuals were provided with the eye-tracking goals and intended outcomes of the data collection. Participants who were willing to continue with the research gave their consent and began the knowledge pre-assessment. Knowledge pre-assessment questions were recorded and later transcribed in order to determine a baseline knowledge level associated with each individual. Once the knowledge pre-assessment was completed, the participant began eye-tracking analysis. Color vision was not assessed for this research, as test environments and time constraints limited protocols found in typical laboratory settings. The eye-tracking pre-assessment included the following questions:

Boiling Water

1. Do you heat or cook your water before you use it? Why or why not?

Hand Washing

1. Can you explain hand washing?
2. Do you wash your hands? Why or why not?

Pit Latrine

1. What is a pit latrine?
2. Do you use one? Why or why not?

Solar Disinfection

1. Can you explain how the sun can purify your water?
2. Do you use the sun to do this? Why or why not?

4.2.3 Calibration and Data Collection

A calibration procedure was administered at the beginning of each eye-tracking session once the participant had completed the pre-assessment. During the calibration process, the individual sat directly in front of a laptop with a stationary eye-tracker attached and followed dots that were displayed at different regions on the computer screen. Each participant was calibrated for software interpolation of the individual differences each person's eyes possess (Bojko 2013). Next, the participant was presented with WSH visualizations (Figures 12-15) on the laptop monitor. Due to the novelty of this experiment and the premise that many participants had never seen a laptop computer, the trial proctor and translator had to set up a working environment that was best suited for the cultural groups. While the participant viewed the visualization, the trial proctor sat to the left of the participant and the translator sat to the right. Both the trial proctor and the translator were cognizant of the eye-tracker's ability to track their own eyes and not that of the participant; therefore, both limited any potential interference by sitting at angles and distances that the eye tracker would not determine. The participant was able to view the visualizations without time constraints. When the participant was ready to move to the next step of the trial, she would speak to the translator in the mother tongue and the proctor would advance the trial to the next step by pressing the SPACE bar on the laptop computer.

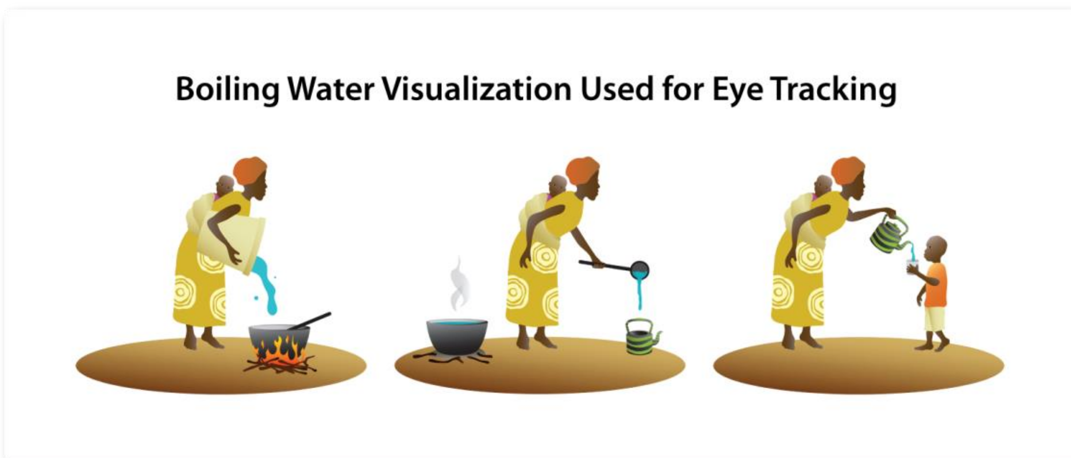

Figure 12. Boiling water visualization used for eye-tracking.
Source: Created by author.

Boiling Water

Post Eye-Tracking Analysis

1. Can you explain the story?
2. What did the woman do with the water?
3. Do you think it's important to do what she did? Why or why not?
4. Do you think the water is safe to drink? Why or why not**?**

What did you like & not like?
Would you change anything?

Figure 13. Hand washing visualization used for eye-tracking.
Source: Created by author.

Hand Washing

Post Eye-Tracking Analysis

1. Can you explain the story?
2. What did the boy do?
3. Do you think it's important to do what the boy did? Why or why not?

What did you like & not like?
Would you change anything?

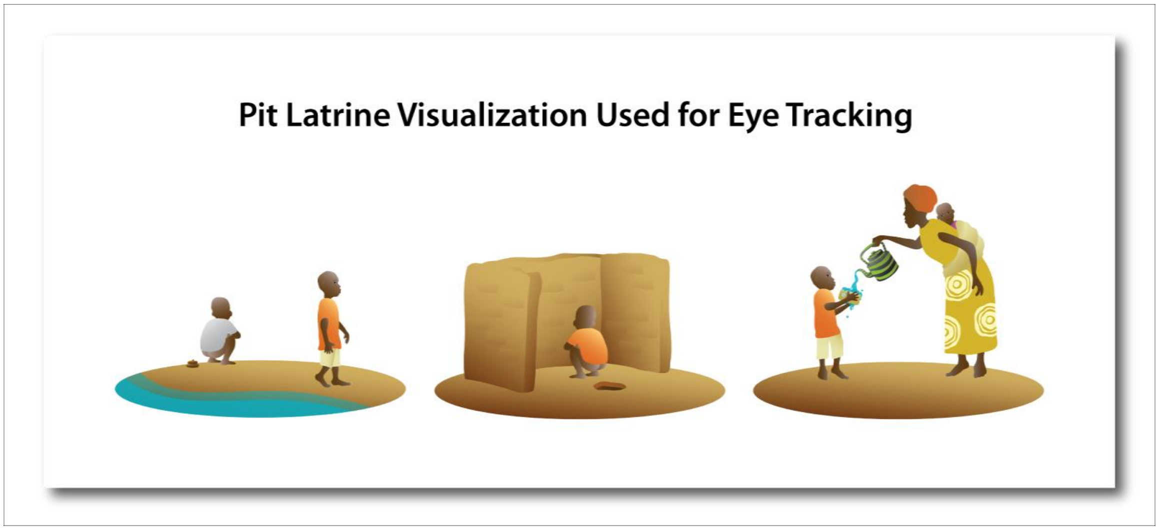

Figure 14. Pit latrine visualization used for eye-tracking.
Source: Created by author.

Pit Latrine

Post Eye-Tracking Analysis

1. Can you explain the story?
2. What did the boy do?
3. Do you think it's important to do what the boy did? Why or why not?

What did you like & not like?
Would you change anything?

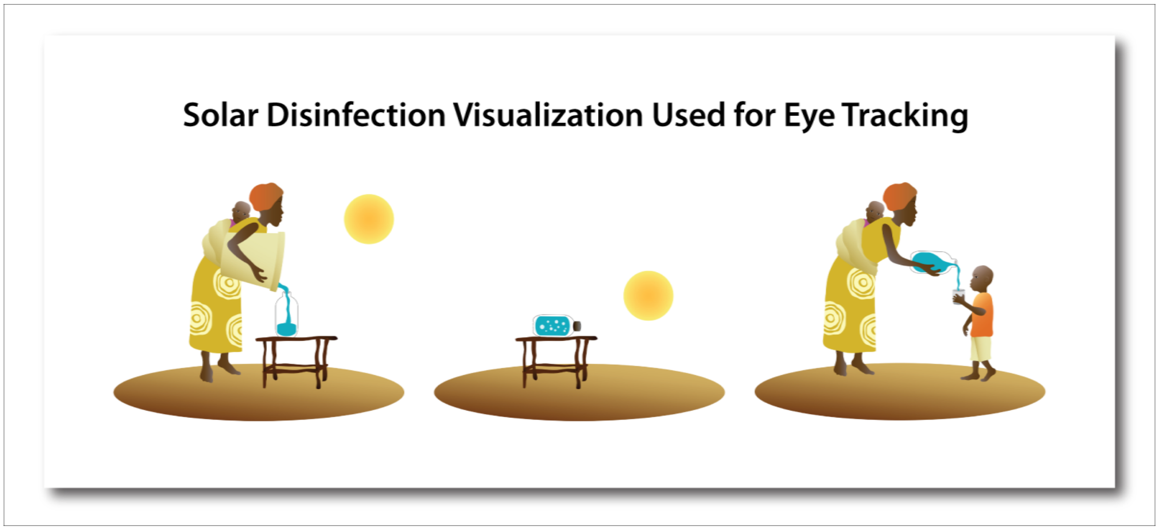

Figure 15. Solar disinfection visualization used for eye-tracking.
Source: Created by author.

Solar Disinfection

Post Eye-Tracking Analysis

1. Can you explain the story?
2. What did the woman do?
3. Do you think the water is safe to drink? Why or why not?

What did you like & not like?
Would you change anything?

4.2.4 Eye-Tracking Post-Assessment

Once the participant concluded the eye-tracking trial, she was immediately given the appropriate post-assessment semi-structured interview questions associated for each WSH visualization. The order of events included: 1) boiling water visualization followed by boiling water questions, 2) hand washing visualization followed by hand washing questions, 3) pit latrine visualization followed by pit latrine questions, and 4) solar disinfection visualization followed by solar disinfection questions. The semi-structured interviews were recorded and later transcribed for further knowledge assessment analysis.

Post semi-structured interviews were transcribed and content was assessed using a scoring rubric (Andrade 2005; Jonsson and Svingby 2007; Reddy and Andrade 2010) for correct and incorrect answers. Participant responses were scored 0 for an incorrect answer and 1 for each correct answer. Each pre- and post-question score was summed in order to provide additional evidence to support the design approach of the WSH educational materials.

4.2.5 Cultural Group Frequencies

Nine different cultural groups were represented in the eye-tracking trials: Fulani, Gourmanche, Hausa, Kado, Kutay, Mori, Songhai, Tamachek, and Zerma. The highest frequency for the cultural groups belonged to Zerma (42 individuals), with Songhai the second highest frequency (40 individuals) (Table 4.4). The two cultural groups with the highest frequencies were used for demographic analysis in the Results and Discussion section of the thesis.

Cultural Group Frequencies for Eye Tracking Trials (104 Participants)

Cultural Group	Fulani	Gourmanche	Hausa	Kado	Kutay	Mori	Songhai	Tamachek	Zerma
Frequency	2	5	1	8	2	1	40	3	42

Table 4. Cultural group frequencies for eye-tracking trials.

4.3 Kernel Density Estimation and Eye-Tracking Quantitative GIS Analysis

In order to quantify the eye-tracking data for this study, raw data, which included participant's fixations and saccades, were exported through Tobii Studio 3.2 and imported into ArcGIS for Desktop 10.2.2. The raw data were then further processed in ArcGIS through the use of eye-tracking tools for more advanced quantitative analysis (Tyrie 2014). In particular, 2D X and Y fixation coordinates exported from Tobii Studio in an Excel file format were imported into ArcGIS, along with the specific visualization to be analyzed. Applicable raw saccade data were extracted for each participant, including X and Y points that corresponded with the specific visualization data, gaze points with the gaze-event fixation type, and the highest validity score of 0 for each eye that was calculated by Tobii Studio 3.2 (Tyrie 2014). Data output, in the form of a GIS shapefile, contained each participant's X and Y valid fixation gaze (saccade) points with spatial coordinates that corresponded to the visualization being analyzed (Figure 16).

Next, Kernel Density Estimation (KDE) analyses were performed on the exported GIS shapefiles. KDE is a type of spatial point-pattern analysis that estimates the density of event occurrences in a predetermined region centered on a search radius (Spencer and Angeles 2007; Xie and Yan 2008; Wang and Wu 2009; Nakaya and Yano 2010; Hart and Zandbergen 2014). For this research, observed regions of interest (event occurrences) from eye-tracking data were used to determine the density of aggregated gaze points. Clusters for event occurrences create "hot spots" in space of the point events. The Kernel Density tool in the Spatial Analyst ArcGIS toolbox was used to perform KDE with an automatic search radius of 27-30 pixels based upon the extent of the visualization and the output cell size set to 0.5 (Tyrie 2014).

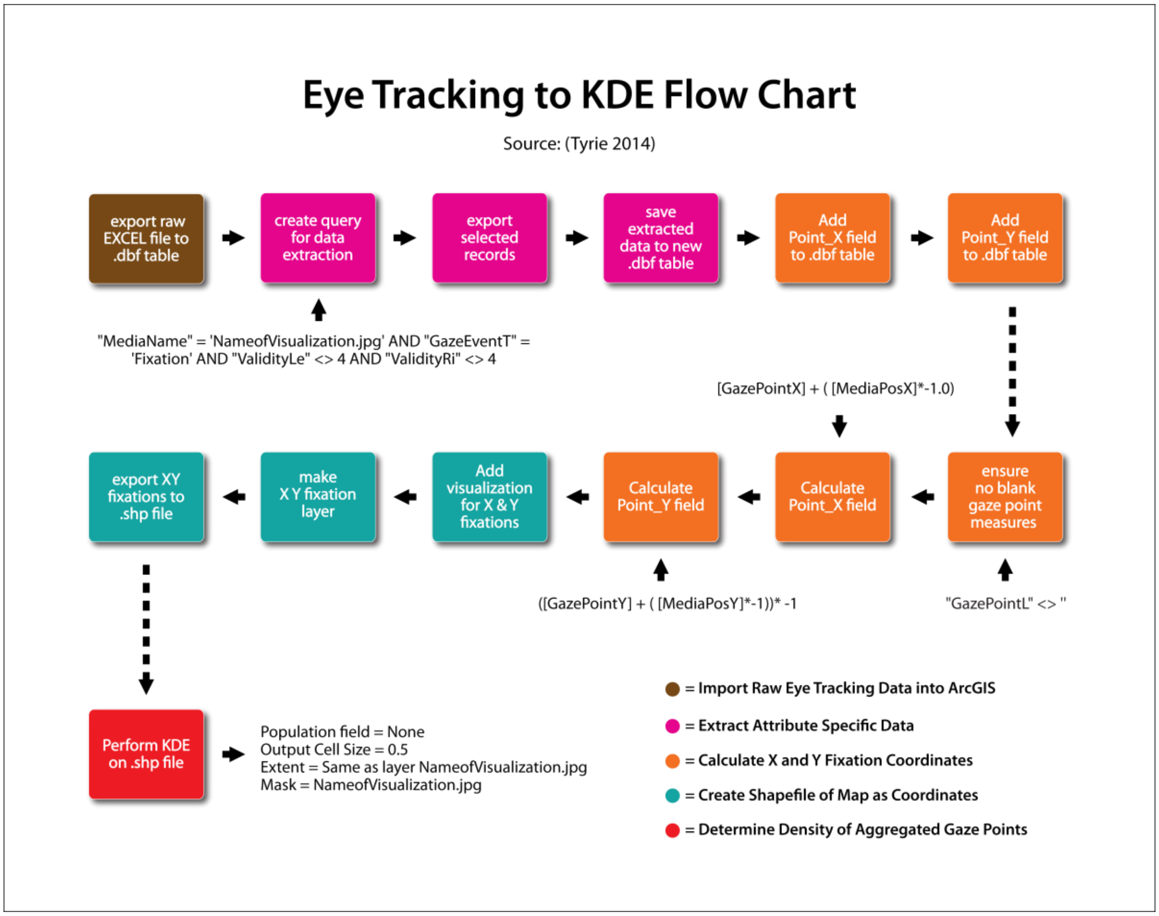

Figure 16. Eye tracking to KDE Flow Chart.
Source: Tyrie (2014).

4.4 Conclusion

This research concentrated on the creation of water literacy communication materials in the form of WSH interventions that are image driven for oral cultures and ethnic groups in rural West Africa. In particular, the role of visual communication as a tool to overcome literacy and language barriers was investigated. Outcomes derived from the evaluation of data show a connection between the research design approach and supportive eye-tracking data. Eye-tracking technology and GIS were used to quantify the design approach effectiveness for the creation of gender- and culture-specific water education materials.

Observations were justified through cross sectional analysis of variables. Cultural limitations for this study included cross-cultural differences, translation and interpretation language biases, and positionality. When conducting research in different cultures Clifford et al. (2012) stated that researchers typically consider strategic approaches used in methods as well as the interpretations developed to be sensitive to inequalities relating to positions of power. Furthermore, the worldview held by primary researchers can affect data collection and interpretations, as well as the way informants will view the researcher in each particular context. Positionality refers to the relationship of the researcher with respect to the subjects (gender, class, status, race, etc.) and the potential ways this can affect the researcher's observations and data collection (Clifford et al. 2012). The use of professional translators and interpreters who are cognizant of cultural languages and customs limited cross-cultural biases associated with language and positionality. Furthermore, cultural data accuracy was further ensured through the use of multiple sources in the forms of indigenous people actively involved as a consultative factor. Thus, any research limitations associated with this study were deemed acceptable due to the inclusion of target populations' consultative involvement, cultural sensitivities, gender specificity, professional translators and interpreters proficient in cultural languages and customs, verbal and graphic design heuristics, qualitative pre- and post-outcome assessments, and quantitative eye-tracking techniques.

Chapter 5: Results and Discussion

The purpose of this study was to determine if visual learning designs could be used to overcome the challenges of water-related health education in oral cultures. Using ethnic groups in rural West Africa as a case study, this research investigated the characteristics of effective water literacy materials, examining how low literacy observers visually process complex visual communication materials and the effect this processing has on the interpretation and understanding of presented material. This thesis research evaluated the effectiveness of sanitation and hygiene, water pollution, and point-of-use water treatment technique visualizations in order to improve observers' understanding of these concepts and to identify the characteristics of instructional visualizations that communicate successfully about them. Results of this study suggest a strong connection between the design methods incorporated and visual learning effectiveness. Learning outcomes found in typical studies were not determined for this research; however, visual learning effectiveness was determined and can be viewed as a novel step in learning assessments. Overall, the research findings offer insight into potential ways in which visual learning design might be used to overcome cultural, societal, and educational challenges in low-literacy populations around the world.

5.1 Focus Groups For Visual Design

5.1.1 Intervention Assets and Barriers

The educational materials created for this research followed established research guidelines that suggest visual aids should consider carefully designs that connect with existing knowledge from the target population, attract the attention of the target population, hold the population's interest, and present data and information in ways that lead to population adherence (Mansoor and Dowse 2004). Focus groups sessions were conducted in fifteen villages along the Niger River to ascertain much of this information. The villages were a mix of varying populations and village types (Table 4.1). Professional translators, who had working relationships with village chiefs and health care workers, chose villages where data were collected. By allowing national partners and hired professionals the task of choosing villages, researcher bias was limited and data collection success was fostered. Although women were recruited for focus groups sessions, male village elders and other village men did participate in the sessions. Eighty percent of the focus group population were women. Interruptions were common during interview sessions, as villagers would take part in conversations and leave as they perform daily tasks.

As noted by Clifford et al. (2012), coding of qualitative data enables a researcher the ability to know their data intimately and see patterns and themes that have emerged. Two categories were used to code the transcribed interviews: what is occurring in the education material and why it is important. Within these categories, specific concepts and constructs were also determined. Patterns emerged that led to a list of assets and barriers to visual learning for the education materials (Figure 17). Assets included: aesthetics that captured attention (Arbuckle 2004); the use of culturally relevant environments (i.e., objects, clothing, landscapes, and people); gender appropriate images (e.g., women related to the type of work and style of dress) (Morris and Stillwell 2003; Carstens 2004); visual storytelling techniques that provoked emotion (Curtis et al. 2011; Duarte 2008); and storyboard pacing of the intervention steps (Duarte 2013).

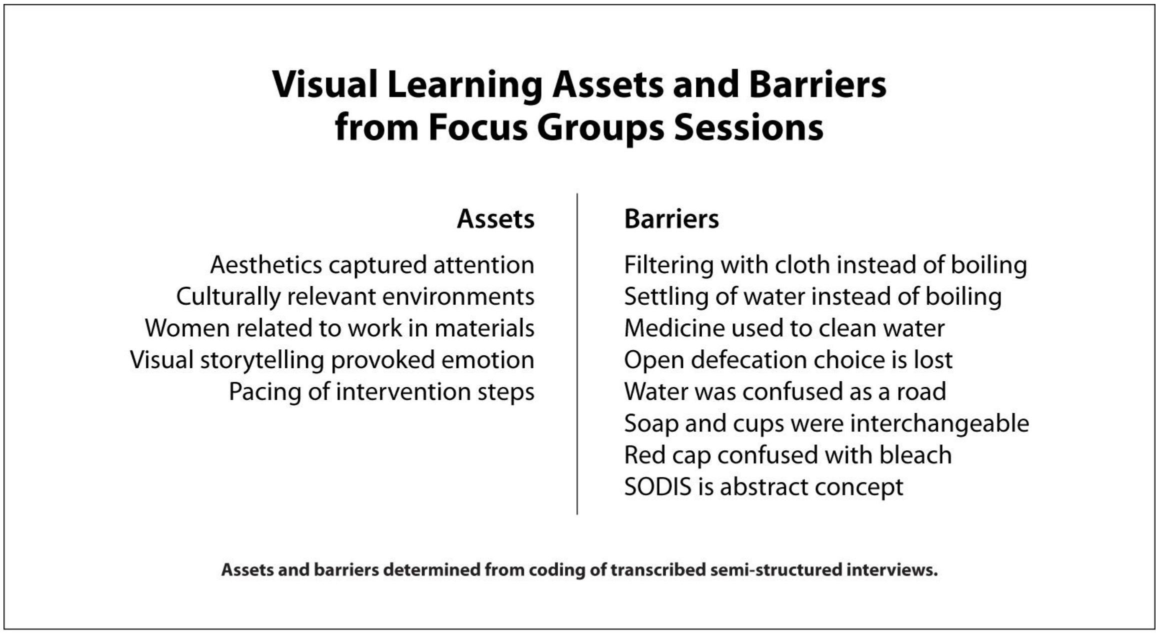

Figure 17. Visual learning assets and barriers from focus groups sessions.
Source: Created by author from focus group sessions.

The use of a mother, her infant child, and her young boy for the storytelling aspect of the education materials proved to be quite useful for capturing attention and provoking emotion among the target audience. It is common among the cultures tested that a mother would never do anything to harm her children. This provided the foundation that the educational materials are important and could be trusted. Women tested related to the woman in the story and the work she was performing, as most water fetching in sub-Saharan Africa is the responsibility of the women and children (Bardasi and Wodon 2006; Ray 2007). Overwhelmingly, the target audience considered the educational materials aesthetically attractive, with many considering the materials works of art. Each intervention included the mother and her two children, which provided familiarity and pacing of the concepts with each intervention building on the next.

Barriers to visual learning uncovered from the coding of focus group interviews included: filtering with a cloth made the water safe to drink (Figure 6); letting the water settle and then dip off the top made the water safe to drink (Figure 6); medicine (tablet) was used to clean the water (Figure 6); the concept in choosing not to defecate openly but instead use a pit latrine was lost (Figure 8); the water in the pit latrine use intervention (Figure 8) was confused with a road; and hand soap and drinking cups were confused with one another (Figures 6-9). Although filtering with a cloth and letting water settle before decanting off the top are viable water treatment techniques, they should not be considered as the endpoint to treatment but rather integral steps in the process. Boiling water and solar disinfection are highly effective in destroying bacteria, viruses and protozoa (McGuigan et al. 1998; Dejung et al. 2007; Rosa and Clasen 2010). The interventions for Boiling Water (Figure 6) and Solar Disinfection (Figure 9) did not include the steps for filtering or settling of water. The decision was made in the early stages of creating the education materials to keep them simple and build upon key concepts for future studies. Therefore, filtering and settling of water were seen as barriers to understanding the visuals and for boiling and solar disinfection interventions.

Participants who failed to understand the visuals for Boiling Water (Figure 6) and Solar Disinfection (Figure 9) interventions commonly stated that medicine was what made the water safe to drink and not the respective intervention. The term ‘medicine’ was revealed to be symbolic of a purification tablet, most likely in the form of chlorine dioxide or *tetraglycine hydroperiodide* commonly used for water treatment. The answers received for chemical use in water treatment stem from humanitarian organizations, non-government organizations, and the Republic of Niger intermittently making purification tablets available to villagers. While purification tablets are effective at destroying bacteria, pathogens, and viruses, chemicals were not used in any intervention for this research and, therefore, were labeled a barrier to visual learning. It is important to note that purification tablets are not routinely available for villagers. In places where they are made available, the costs are too high for them to be affordable and, therefore, they are generally not used.

Two barriers to visual learning were identified in the pit latrine use intervention (Figure 8). This intervention was the only one of the set (Figures 6-9) that included a decision or choice to be made. The boy character chooses not to defecate openly by the water like the others and instead chooses to use a pit latrine. Those who failed to understand the visuals often missed the choice concept and looked directly at the pit latrine use in the story. In addition, the water in the visualization (Figure 8) was not recognized as such and was commonly referred to as a road. Water was important to incorporate in the pit latrine intervention to educate about the connection between the high open-defecation prevalence (81%) found in Niger, where it is very common for people to defecate in and around waterways (Galan et al. 2013).

Another barrier identified through the focus group data was that hand soap and drinking cups were often confused for one another (Figures 6-9). Hand soap is not usually found in villages due to its high cost. Diarrheal mortality and morbidity is largely a disease of the impoverished, and soap is most commonly not found among these populations. Even when soap is readily available, hand washing with soap is not a common practice among the target population due to deeply rooted cultural and societal hygiene practices; yet, hand soap was included as the best-case scenario for the health interventions. Hand washing with water alone could be seen as a first step to total hand washing, as microbiological studies have demonstrated that washing hands with water alone reduces the concentration of various types of bacteria on hands (Lowbury et al. 1964; Ansari et al. 1989) and often was mentioned as the ways in which the boy was rinsing his hands to clean them.

The last two visual learning barriers determined from the focus group data were for solar disinfection (SODIS); these barriers were the red cap on the plastic bottle used in the water storage process of SODIS being confused for bleach, and SODIS being an abstract concept to most participants. In larger villages, bottles of liquid bleach, with a red cap on the lid, are prevalent. This could explain answers that 'medicine' was used to treat the water in the SODIS visualization. Further, national partners and hired professional translators explained that solar disinfection is an idea that most inhabitants had never considered before. The idea that the sun could have energy used to make the water clean was very profound. Education levels in Niger are nominal, with an adult literacy rate of 15% (UNESCO 2012) and a female literacy rate of 9% (Grote and Warner 2010). Niger's water supply deficiencies, and its associated implications, are deeply rooted in poverty, underdeveloped infrastructure, and overexploited supplies that constrain the country's ability to address water issues and educate about them. Approaches and compliance for SODIS interventions can be difficult, especially in low-literacy and low socio-economic environments; yet, this intervention has shown great promise in various cultures (Rose et al. 2006) and was included due to abundant solar energy in Niger (Peel et al. 2007).

5.1.2 Intervention Enhancements

The aforementioned assets and barriers determined from the coding of the focus group data (see Figure 17) were the foundation for enhancing the visualizations that were to be used in the next phase of the research. In an effort to increase effectiveness for the WSH interventions, focus group visual learning assets and barriers were studied in detail. Assets were kept in the newly designed WSH visualizations and built upon, while barriers were alleviated as much as possible.

Enhancements for the boiling water visualization included the removal of distracting elements to simplify the design (e.g., water storage pots). Although the water storage pots are culturally relevant and found throughout the study area, they are not affordable by most rural populations and, thus, are an item that is not relatable by most of the population. In addition, confusion surrounding the treatment process was evident, as many thought filtering with cloth and decanting off settled water was the type of water treatment occurring in the visualization. The cup used by the boy for drinking water was made bigger to help complete the story that the boy was drinking clean water his mother had boiled. Steam was added over the cooling pot to help visualize the boiling process. Seven steps for the intervention were simplified to three, which provided storyboard pacing of the steps in an easy format (Duarte 2013). Consultative design enhancements for the boiling water visualization are shown in Figure 18.

Figure 18. Consultative design enhancements from target population for boiling water visualization.
Source: Created by author from data collected during focus groups sessions.

Design enhancements for the hand-washing visualization included the reduction of intervention steps and increasing the size of the bar of soap used by the boy. Since one barrier for the hand-washing visualization was that the soap was often confused for a drinking cup, signifying the boy was drinking water before he ate and not washing his hands, the focus of the visual redesign was on the hand-washing step. Specifically, the soap size was increased, and soap bubbles and water flowing from the water pitcher the mother is using to pour over the boy's hands were added in an attempt to decrease confusion surrounding the key constructs of the intervention. Disgust was determined from the focus groups as a motivating factor for hand washing, as hands need to be washed when they were contaminated with organic matter that is dirty, foul, or odorous. Intervention steps were reduced from four to two in order to promote better understanding and recall of hand washing steps. Consultative design enhancements for the hand washing visualization are shown in Figure 19.

Figure 19. Consultative design enhancements from target population for hand washing visualization. Source: Created by author from focus groups sessions.

Pit latrine visualization design enhancements included the reduction of steps for the intervention, removal of distracting elements, design focus on the decision not to defecate openly, making soap more discernible, and designing water in a way that better represented a typical shoreline of the Niger River. As seen with the boiling water and hand-washing enhancements, intervention steps were reduced from seven to three to assist with the storyboard pacing and with comprehension for visual thinking processes (Ware 2008; Duarte 2008; 2013). As aforementioned, one of the key concepts for the pit latrine intervention is the choice aspect where the boy chooses not to defecate openly and instead uses a pit latrine. In the focus group pit latrine visualization, two boys were about to defecate by the water. One of the boys was removed to minimize distraction and the remaining boy was designed in the act of defecating. This may seem inappropriate for other cultures, but with an open defecation rate of 81%, it is very common and not unlikely for this act to be conducted near waterways and in the bush environment of Niger. The bar of soap was designed to be more discernible in the intervention to promote hand washing after defecation. Consultative design enhancements for the pit latrine visualization are shown in Figure 20.

Based on the focus group data, solar disinfection was the intervention least known among target populations. Solar disinfection is a concept that was not recognized by most participants and not considered as a way to treat drinking water successfully; however, SODIS is a viable option for deactivating bacteria, pathogens, and viruses within the study area of Niger (Rose et al. 2006; Peel et al. 2007). The red cap on the plastic bottle used in the sterilization process was replaced with a black cap to mitigate confusion surrounding the red caps commonly found on bleach bottles. Nine intervention steps were reduced to three to simplify the abstract concept of SODIS. The sun was designed in a way that represented time had passed as it lowered on the horizon. Water does not have to be boiled to kill microorganisms.

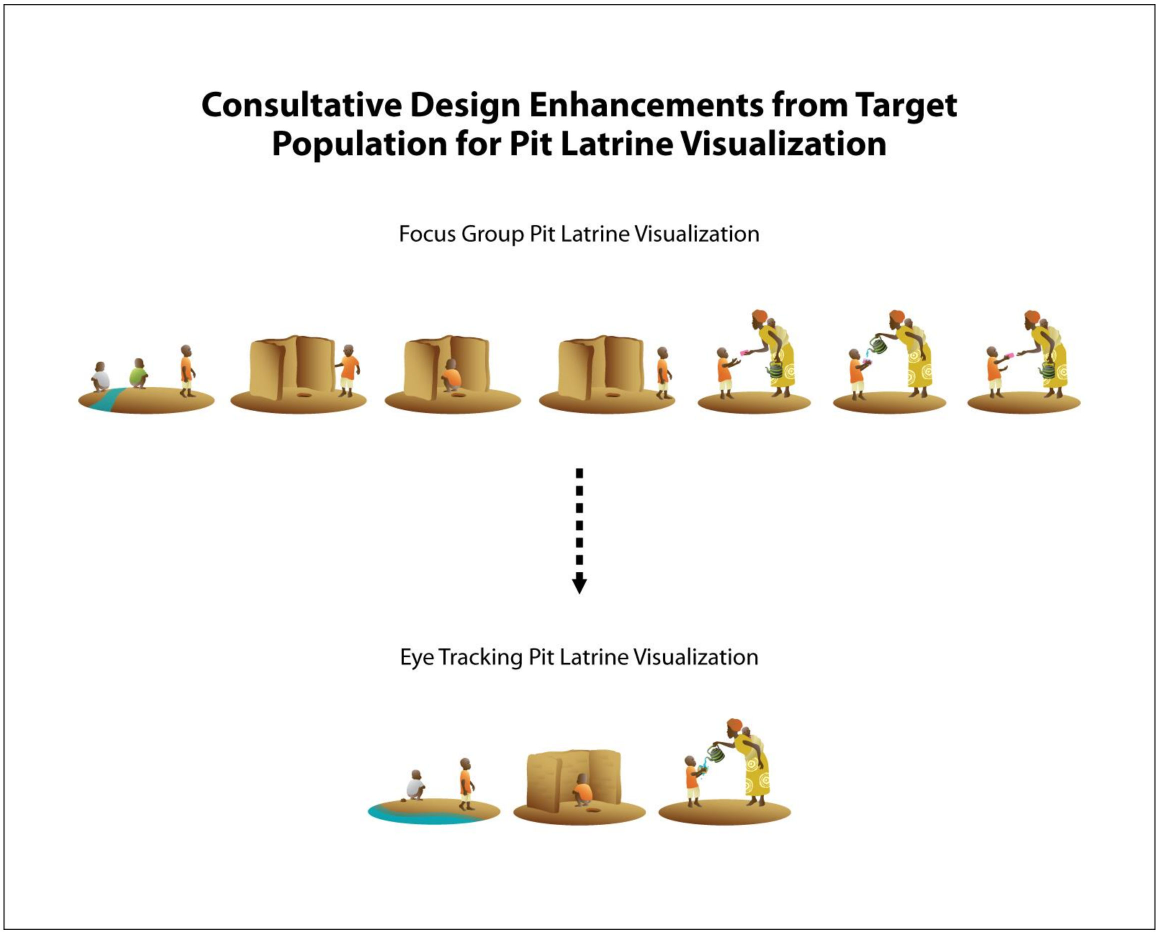

Figure 20. Consultative design enhancements from target population for pit latrine visualization. Source: Created by author from focus groups sessions.

Thus, heating the water to an elevated temperature (55°C) over an extended period of time has the same effect as boiling (Metzler et al. 1994; Joyce et al. 1996) and was an integral component in the design of the sun lowering on the horizon. Bubbles were added to the solar disinfection visualization to represent the heating of water inside the translucent plastic bottle. A handmade wooden table that could be found among target populations was added for a place to rest the plastic bottle while the water is being sterilized by the sun's energy. The rock on which the plastic water bottle sat and the water storage pots were removed from the visualization, since they were deemed distractions for understanding key concepts. All four of the enhanced WSH visualizations incorporated the use of white space to draw the user's attention to the visualizations (Carstens 2004). Consultative design enhancements for the solar disinfection visualization are shown in Figure 21.

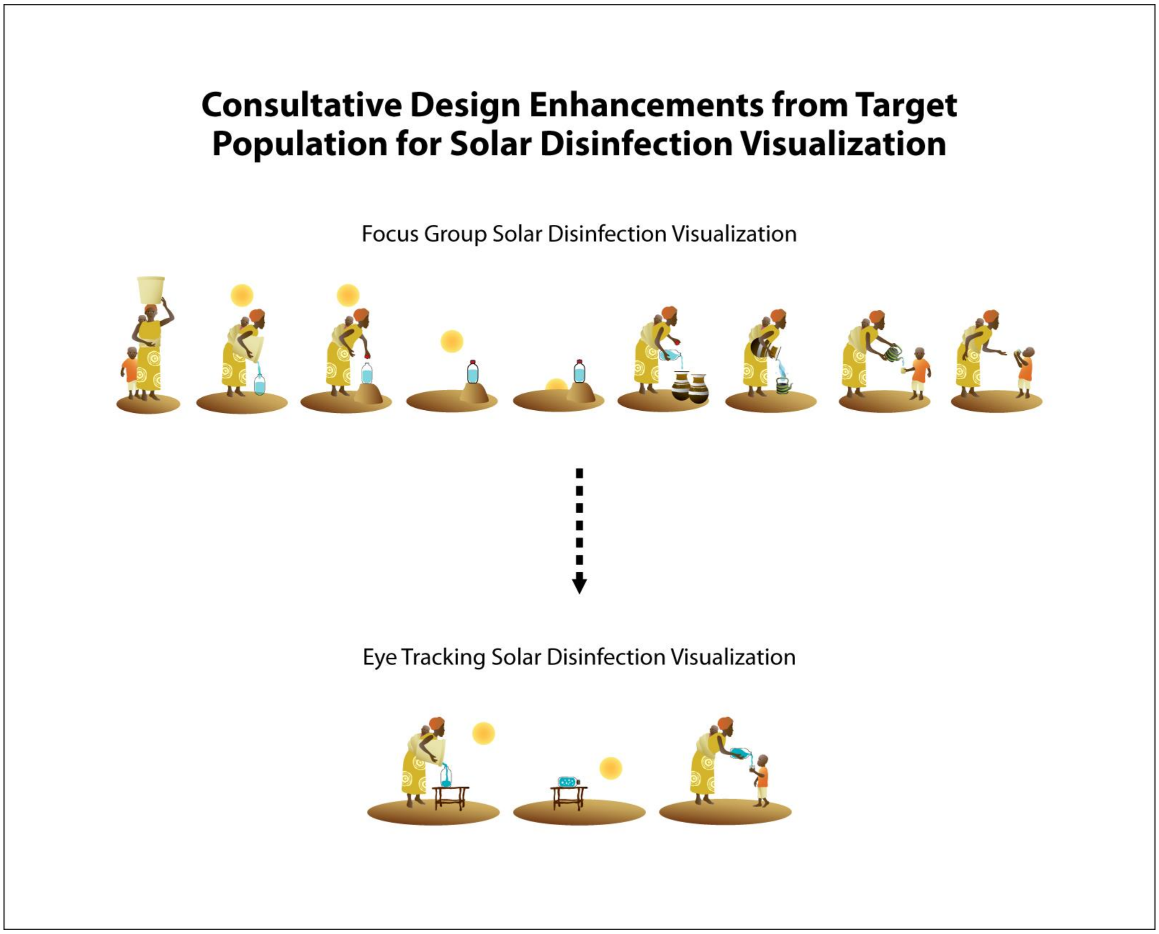

Figure 21. Consultative design enhancements from target population for solar disinfection visualization. Source: Created by author from focus groups sessions.

5.2 Visual Learning

Data from eye-tracking trials indicated users spend more time fixating on certain graphical elements and visual stimuli; however, the data also require supplemental evidence collected through semi-structured interviews and outcomes assessments, to further support suggested theories. Kernel density estimations (KDE) were also used to quantify the regions of interest (ROI) for observers. Specifically, KDE was used to quantify the design approach, providing evidence that the graphical design of health interventions promotes learning (i.e., observers are not distracted by design elements, but rather, focus on key constructs and concepts). By mapping the kernel density of each intervention, the areas of the graphics that users fixated on were determined that, overall, led to improved design and educational effectiveness.

5.2.1 Establishing Knowledge Base Levels

Pre- and post-assessment interviews for eye-tracking trials were transcribed in order to determine knowledge base levels. Nearly 24 hours of audio interviews were recorded during pre-knowledge assessment sessions and the post visual learning effectiveness assessments. Qualitative data were coded (Clifford et al. 2012) and content measured applying the same methods as used on the focus group data sets (Andrade 2005; Jonsson and Svingby 2007; Reddy and Andrade 2010). Participant responses were scored 0 for an incorrect answer and 1 for each correct answer, with 2 being the highest score possible. Each question score was summed in order to determine the pre-knowledge base levels and visual learning effectiveness assessments (Table 5).

Total Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	104	1.34 (67%)	1.95 (98%)	1.55 (78%)	0.27 (14%)
VLE	104	1.06 (53%)	1.14 (57%)	1.49 (75%)	0.87 (42%)

KBL = Knowledge Base Level VLE = Visual Learning Effectiveness Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 5. Total population qualitative measurements for eye-tracking trials.

Existing knowledge of water education material topics was evaluated before each eye-tracking trial began. Knowledge base levels (KBL) for the total sample population included: boiling water at 1.34; hand washing at 1.95; pit latrine at 1.55; and solar disinfection at 0.27. The hand washing KBL of 1.95 signifies a strong knowledge base for understanding hand-washing protocols and procedures. Hand washing with soap is considered the most cost-effective of all major disease control interventions (Fewtrell et al. 2005; Bartram and Cairncross 2010). The education for this intervention is apparent and well represented among the target population. Solar disinfection KBL was the lowest of all measured. As previously noted from the focus groups' interview sessions, solar disinfection's low KBL corroborates the subjective opinions of hired translators who indicated that SODIS was an abstract concept that most members of the population had never heard of before.

Eye-tracking trial post-assessments were designed with cogent questions in order to predict graphical effectiveness by measuring correct answers for core constructs of health interventions being recalled in the interview. Each question score was summed for each assessment in order to determine the visual learning effectiveness for each intervention (Table 5). The same scoring rubric scale that was used in the focus groups' sessions was used for the eye-tracking trials data sets where the two categories for coding the data included what is occurring in the intervention visualizations and why it is important. Visual learning effectiveness (Table 5) for the eye-tracking trials included: boiling water at 1.06; hand washing at 1.14; pit latrine at 1.49; and solar disinfection at 0.87. The pit latrine intervention visualization had the highest score for visual learning effectiveness (VLE) with 1.49. Solar disinfection levels for VLE were the lowest of all measured. As previously mentioned, low levels for solar disinfection can be contributed to the abstractness of SODIS to the target population.

5.2.2 Eye-Tracking Qualitative Data: Assets and Barriers

Patterns and themes emerged from the coding of the eye-tracking trial post-assessment data (Clifford et al. 2012), comparable to those discovered from the focus group sessions' data sets (Table 2). Key concepts and constructs were determined that led to a list of assets and barriers to visual learning for the education materials (Figure 5.6). Assets that were found in the focus groups' sessions were also found in the eye-tracking qualitative data: aesthetics that captured attention (Arbuckle 2004): the use of culturally relevant environments (i.e., objects, clothing, landscapes, and people); gender appropriate images (e.g., women related to the type of work and style of dress (Morris and Stillwell 2003; Carstens 2004)); visual storytelling techniques that provoked emotion (Curtis et al. 2011; Duarte 2011); and storyboard pacing of the intervention steps (Duarte 2013). New assets, which were previously barriers (Figure 22), developed from the target population enhancements: the choice not to defecate openly was noticed for the pit latrine visualization (Figure 14); water was no longer confused as a road (Figure 14); bleach no longer mentioned as a treatment technique (Figure 15); and filtering with cloth and settling of water was less common an answer (Figures 12 and 15).

Barriers to visual learning uncovered from the coding of the eye-tracking post-assessment data included three barriers found previously in the focus groups' sessions (Figure 22): medicine was used to clean water (Figure 15), soap and cups are interchangeable (Figures 12-15), and solar disinfection is an abstract concept to the target population (Figure 15). Two new barriers were also revealed in the data set: the mother gave her child hot water to drink (Figure 12) and the bubbles used in the solar disinfection visualization are undesirable (Figure 15). The concept that the mother gave her child hot water to drink from the boiling water visualization (Figure 12) was viewed as something a mother would never do, as this would harm her child. Participants who failed to understand the visualization often did not see the water had cooled before it was given to the child to drink. Bubbles were added to the solar disinfection visualization (Figure 15) to represent the heating of water inside the translucent plastic bottle. This design enhancement was often viewed by participants who failed to understand the intervention as a contaminant within the bottle, and led to the water being undesirable to drink.

Visual Learning Assets and Barriers from Eye Tracking Trials

Assets	Barriers
Aesthetics captured attention	Medicine used to clean water
Culturally relevant environments	Soap and cups were interchangeable
Women related to work in materials	SODIS is abstract concept
Visual storytelling provoked emotion	Giving the boy hot water to drink
Pacing of intervention steps	Bubbles in bottle are undesirable
Open defecation choice noticed	
Water no longer confused as road	
Bleach no longer mentioned	
Filtering with cloth less common	
Settling of water less common	

Assets and barriers determined from coding of transcribed semi-structured interviews.

Figure 22. Visual learning assets and barriers from eye-tracking trials.

5.2.3 Kernel Density Estimations

KDE was used to determine the regions of interests (ROI) observed by the participants in each dataset through the density of fixation points. Specifically, raw eye-tracking data for this study, which included participants' fixations and saccades, were exported through Tobii Studio 3.2 and imported into ArcGIS. From the visual path data, the visual behavior trends of individuals and aggregated groups, such as cultural and age groups and education levels, were determined and quantified. KDE demographic categories for analyses included total participants (Figure 23); educated versus uneducated (Figure 24); ages 14 to 35 versus ages 36 to 75 (Figure 25); market villages versus non-market villages (Figure 26); and Songhai versus Zerma cultural groups (Figure 27). Participants' visual paths were analyzed across each intervention graphic. The presence or absence of coordinates (eye data points in X and Y coordinates) allowed the opportunity to answer fixation-related questions (i.e., which graphical elements were seen, when a graphical feature captured attention and duration, and what graphical content was overlooked) (Bojko 2013). For this research, KDE hot spots were mapped using a color spectrum from blue to red. The more intense the color red, the denser are the ROIs for that area of the visualization. The KDEs were used to explore the eye-tracking data further, and they helped to determine if graphics were confusing to individuals. As noted by Bergstrom (2014), eye-tracking allows researchers the ability to comprehend the complete and complex user experience, even that which users cannot describe or explain. Combining eye-tracking data with data from pre- and post-assessments more accurately assessed visual learning. Larger versions of kernel density estimation eye-tracking visualizations are provided in Appendix A.

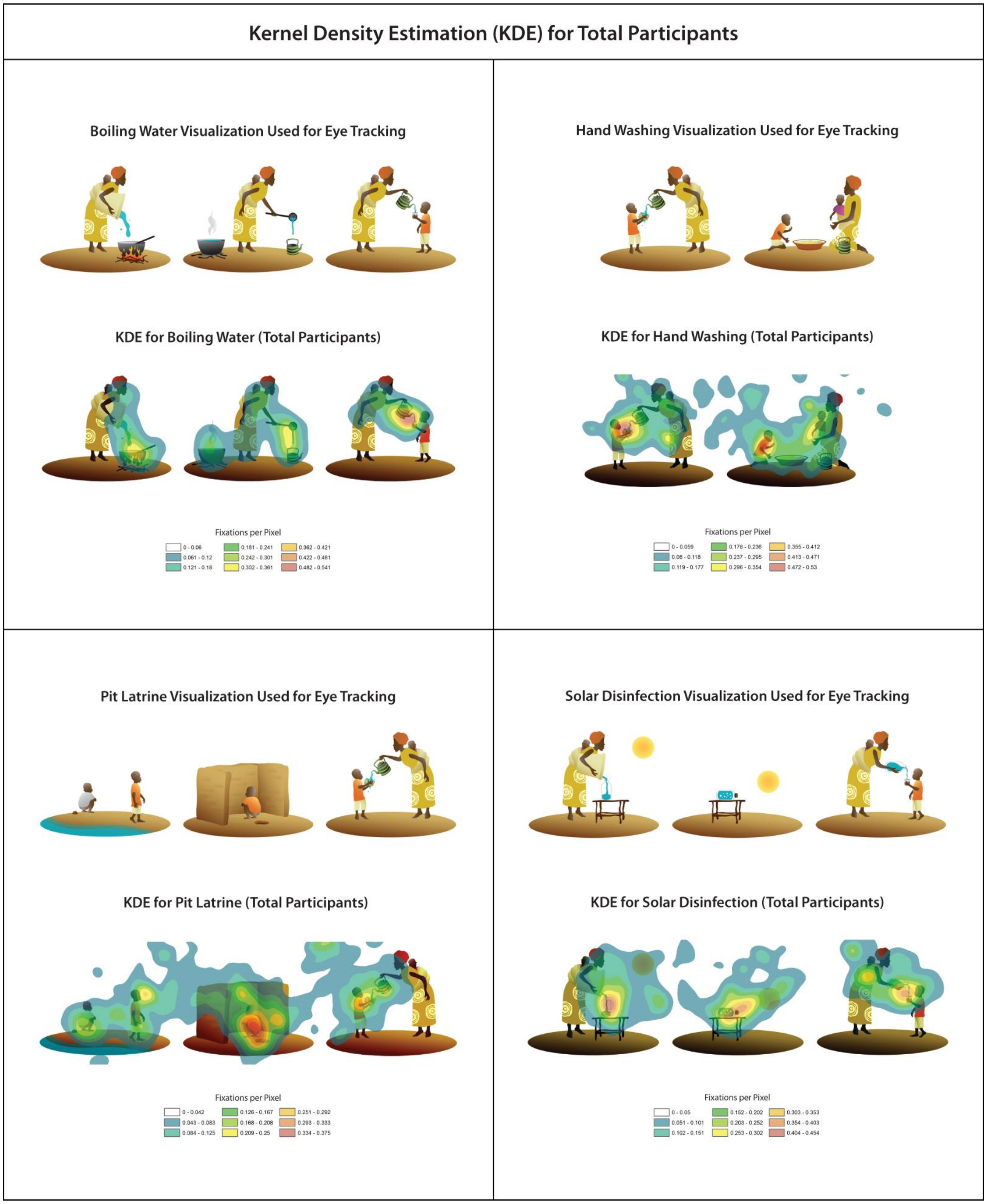

Figure 23. Kernel density estimation (KDE) for total participants.
Source created by author from eye-tracking trials.

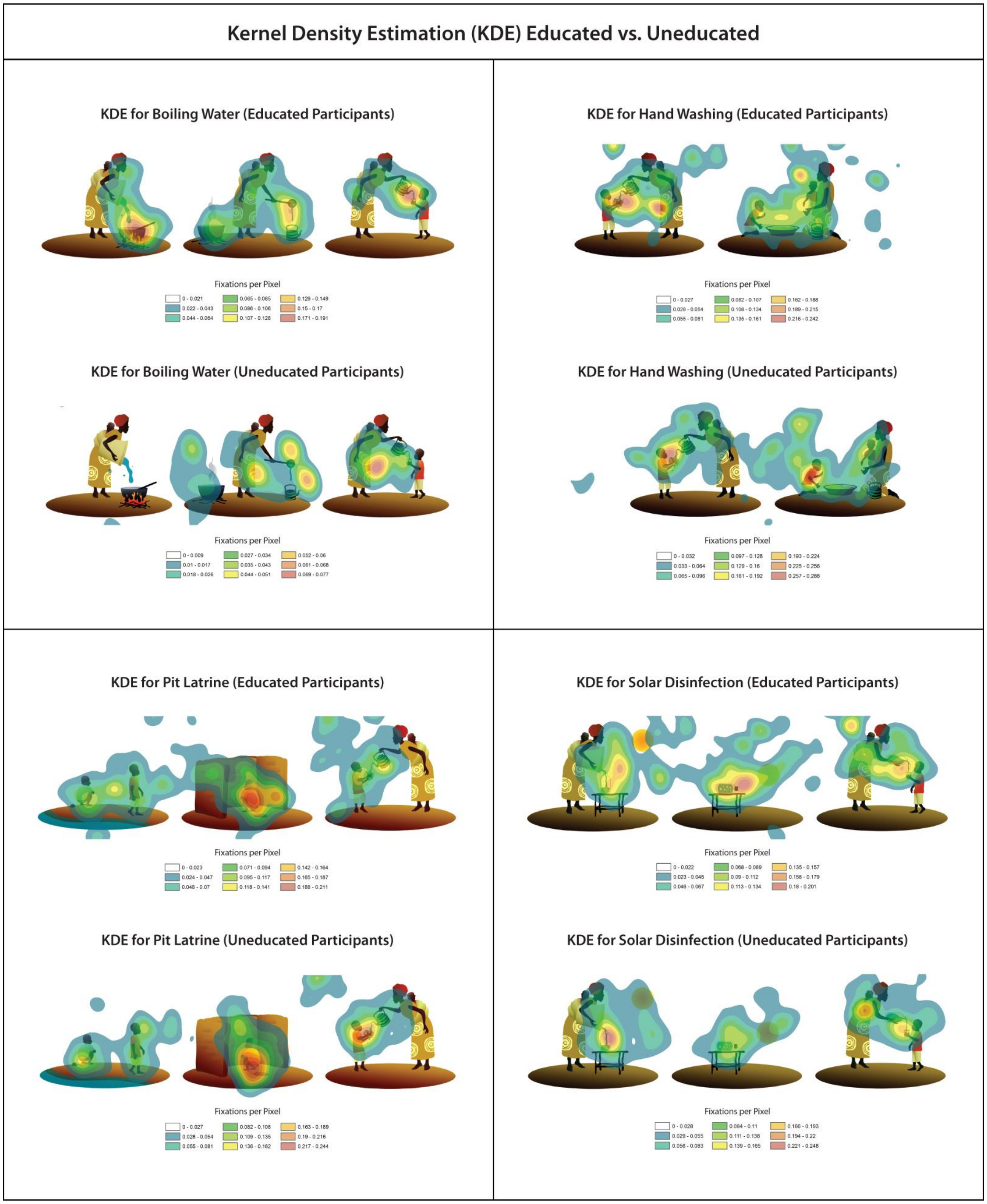

Figure 24. Kernel density estimation (KDE) educated vs. uneducated.
Source created by author from eye-tracking trials.

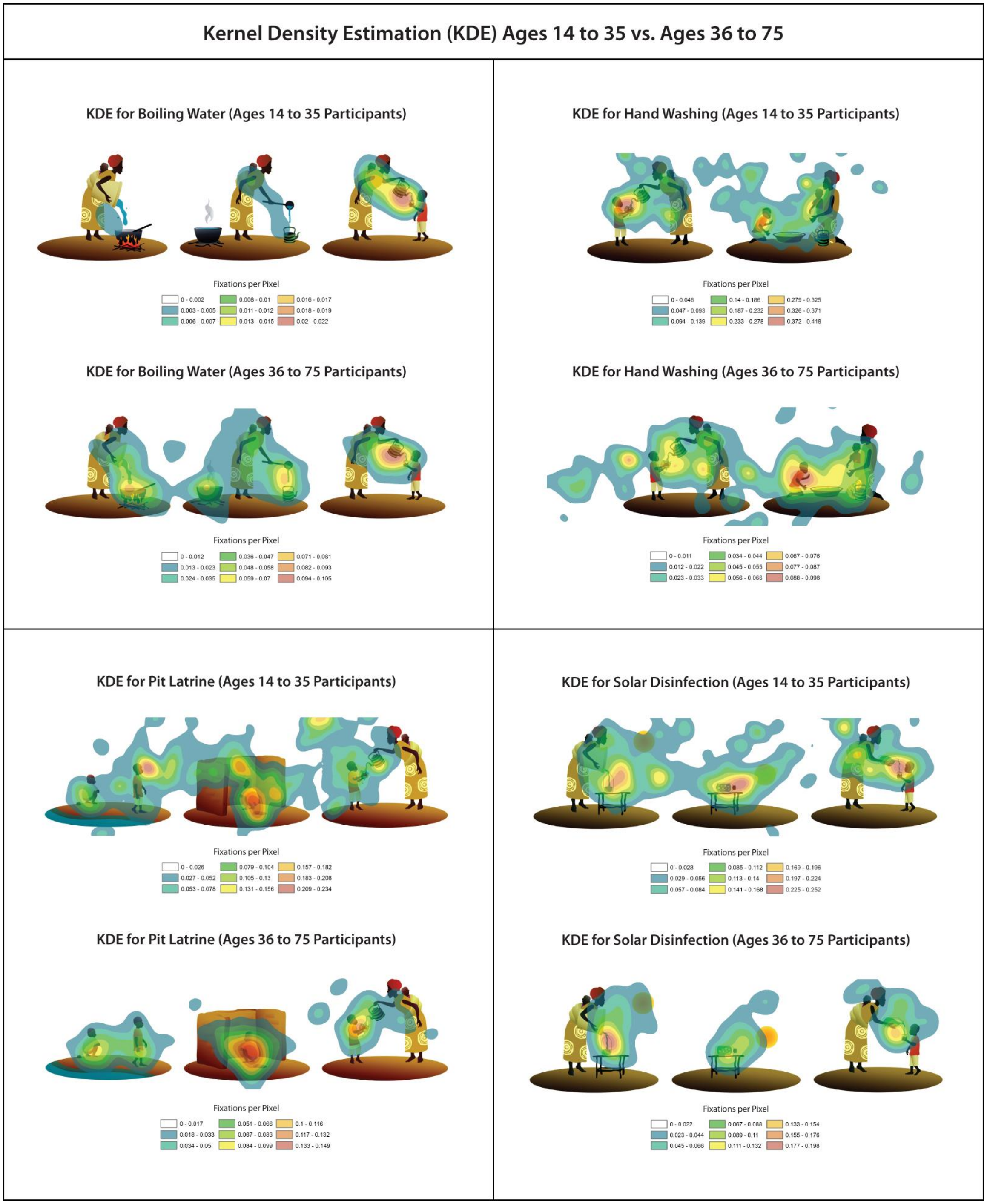

Figure 25. Kernel density estimation (KDE) Ages 14 to 35 vs. Ages 36 to 75.
Source created by author from eye-tracking trials.

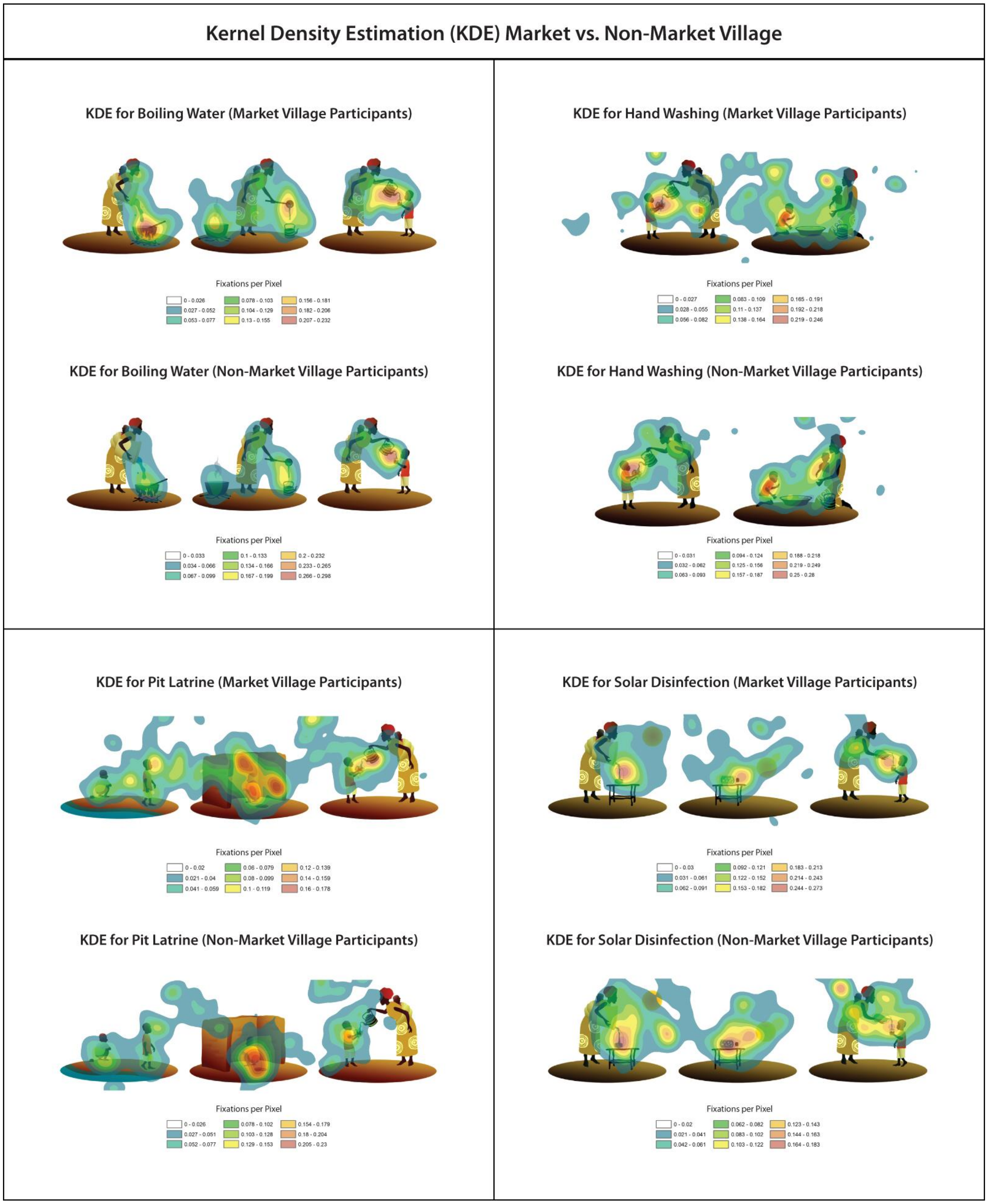

Figure 26. Kernel density estimation (KDE) market vs. non-market villages.
Source created by author from eye-tracking trials.

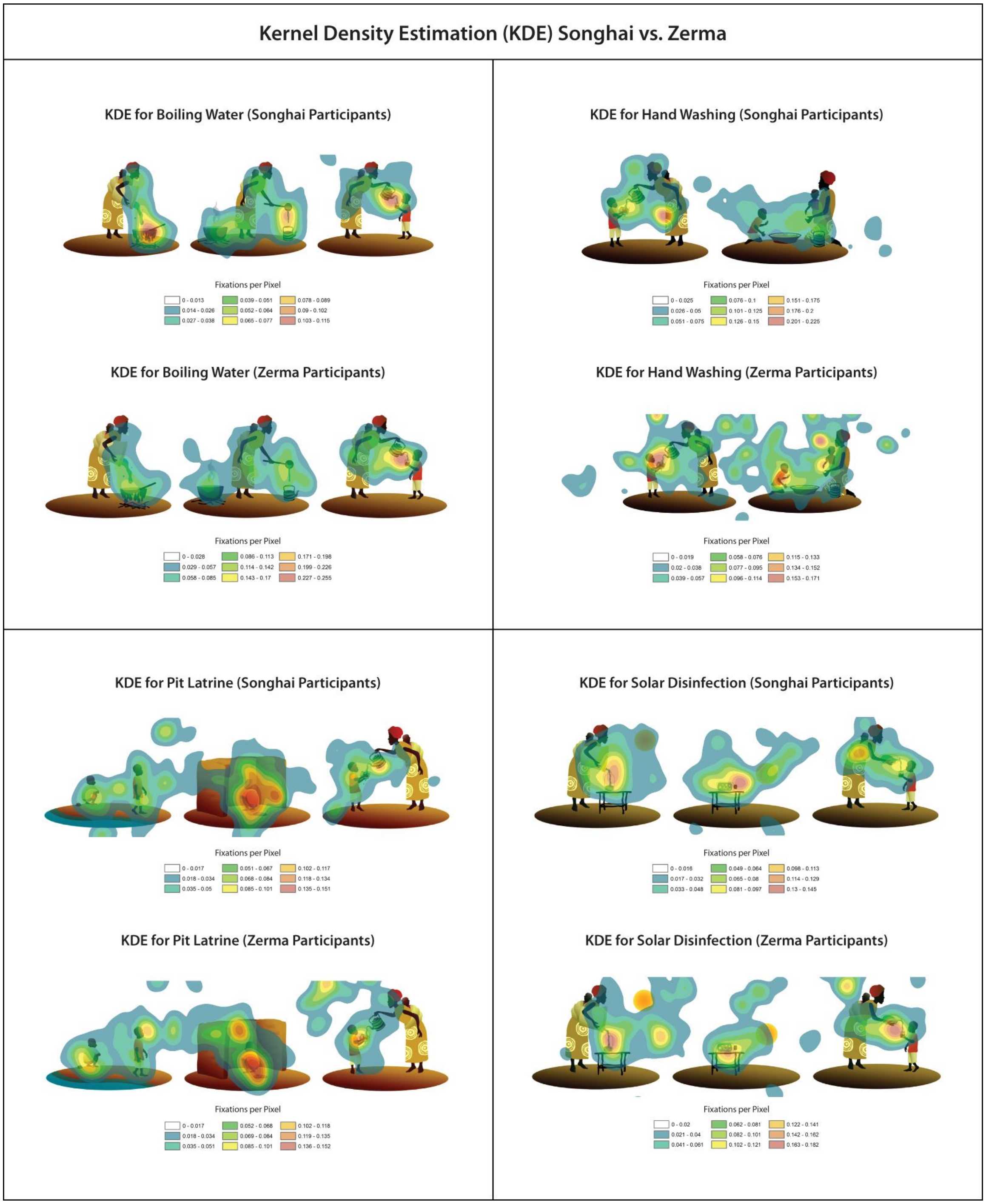

Figure 27. Kernel density estimation (KDE) Songhai vs. Zerma.
Source created by author from eye-tracking trials.

KDEs were performed on 104 participants' observed regions of interest to determine the density of aggregated gaze points. The Boiling Water KDE (Figure 23) map revealed participants' regions of interest to be closest spatially to the key constructs of the intervention graphic: the pouring of fetched water into the pot to boil, the cooling pot and mother pouring water into a water storage pot, and the mother pouring water from a water storage pot into a cup for a child to drink (Figure 28). The boiling pot, water flowing into the water storage pot, and the water flowing from the water pot into the child's cup are the ROI densest areas, which is the objective for the visual learning design of the visualization. The location, duration, and movement of fixations are used to establish the eye-gaze pattern that reflects how the user interprets a particular visual stimulus, which provides the foundation for understanding the visual hierarchy of a scene (Djamasbi et al. 2011; Bergstrom 2014). Visual hierarchy refers to the arrangement of the graphical elements in ways that influence the order of importance the human eye perceives and dictates an individual's attention and duration (Wade and Sommer 2006; Jackson 2008; Djamasbi et al. 2011; Bergstrom 2014). The visual hierarchy for the Boiling Water visualization was designed to capture the attention at the key constructs previously mentioned, a goal strongly supported by the KDE.

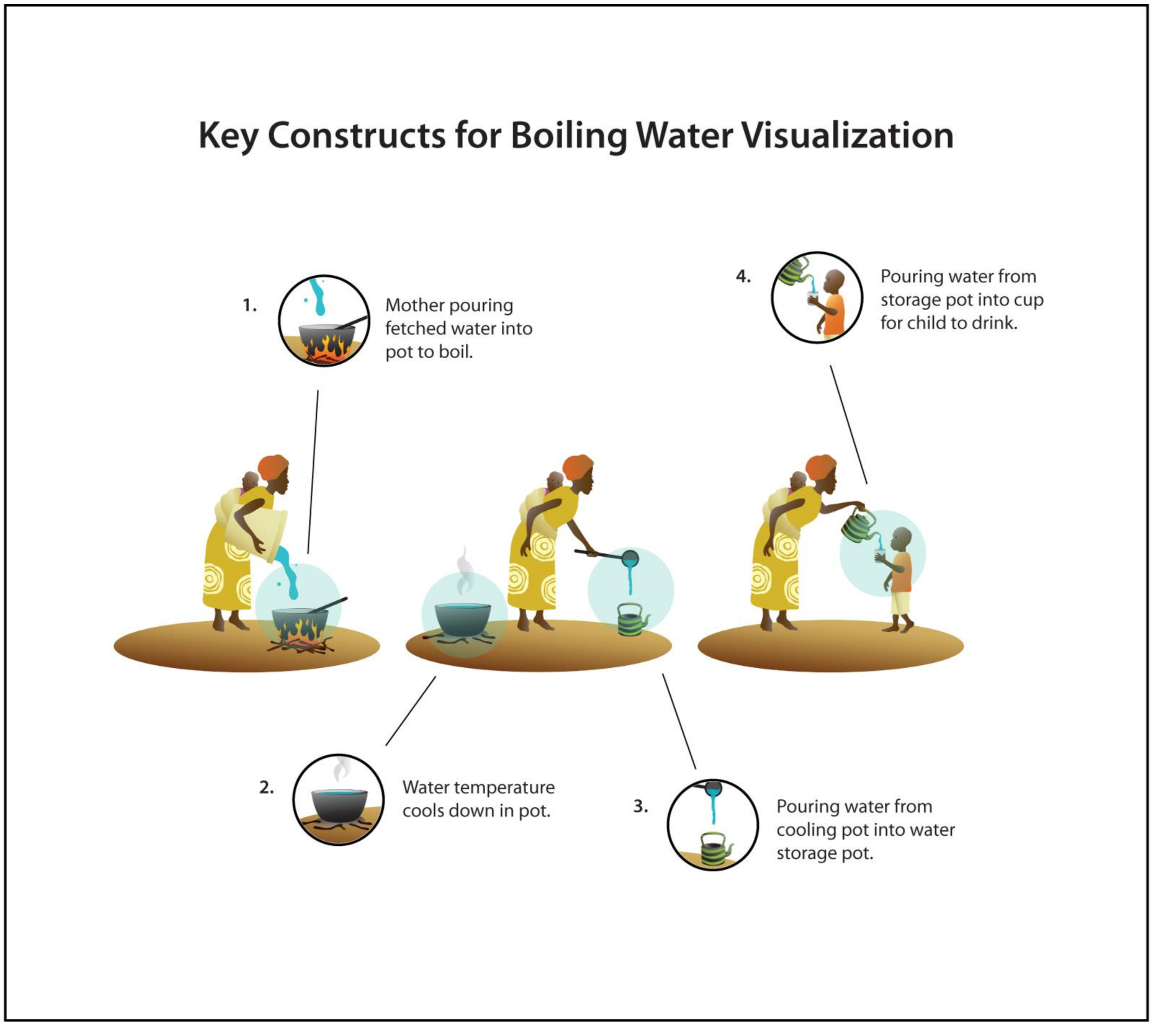

Figure 28. Key constructs for Boiling Water Visualization.
Source: Created by author.

The KDEs for Hand Washing, Pit Latrine, and Solar Disinfection for the study population were not as uniform as the Boiling Water KDE (Figure 23). Participants' ROIs were more sporadic for these kernel density estimations; yet, the densest aggregated gaze points (red map color) were found on the key constructs and concepts for each of the intervention visualizations. The Hand Washing intervention's key components were the boy washing his hands and the mother and son eating food (Figure 29). The key components for the Pit Latrine intervention were: one boy is openly defecating by the water while the other boy walks past him, the boy defecates in the pit latrine, and the boy washes his hands (Figure 30). The solar disinfection key components were water being poured into plastic bottle, water lies on table in the sun, and finally the boy gets a drink of water (Figure 31). The ROI densest areas of the KDE for hand washing, pit latrine, and solar disinfection (Figure 23) coincided with the key components of each intervention, which indicates the visuals promoted learning and recall.

Figure 29. Key constructs for Hand Washing Visualization.
Source: Created by author.

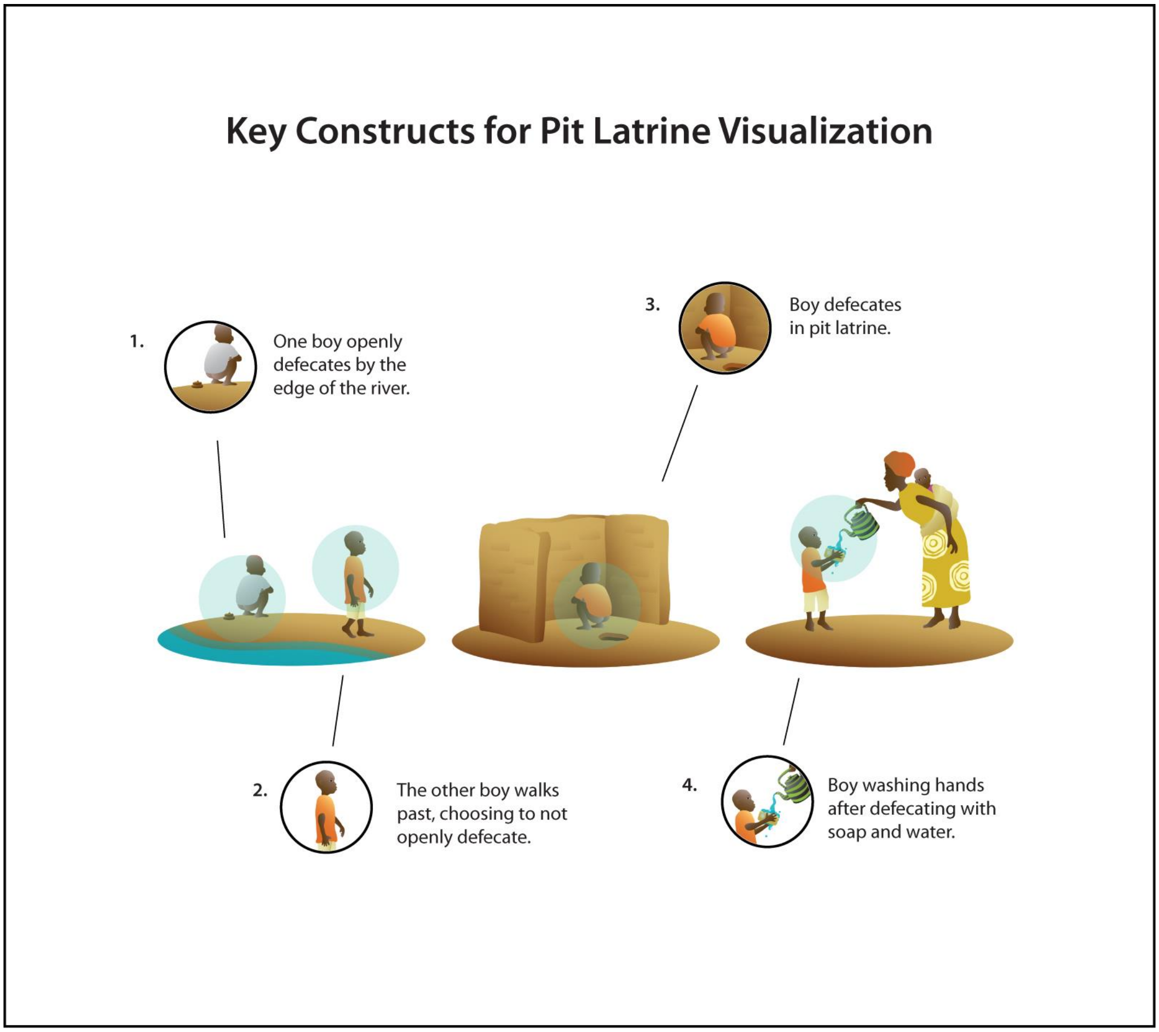

Figure 30. Key constructs for Pit Latrine Visualization.
Source: Created by author.

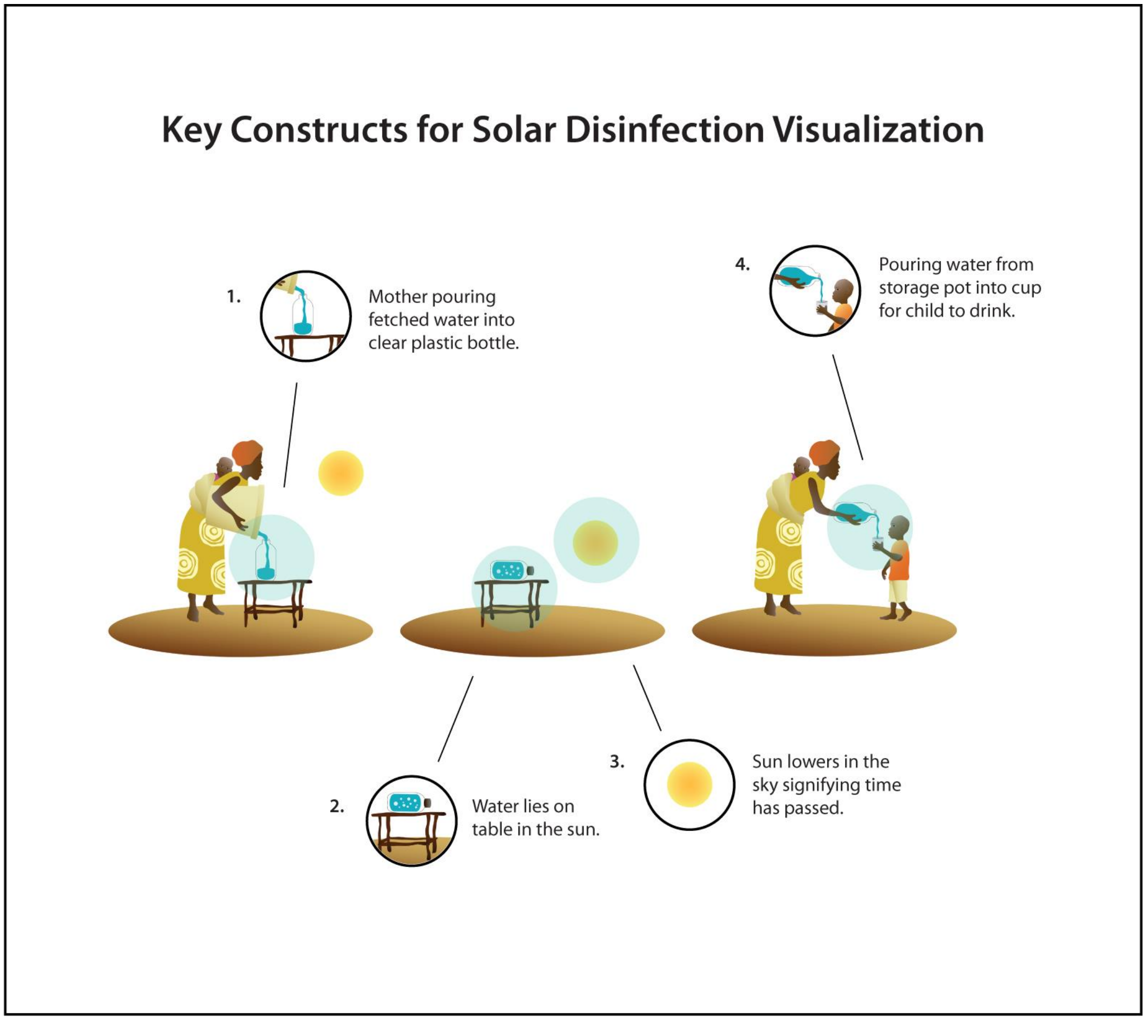

Figure 31. Key constructs for Solar Disinfection Visualization.
Source: Created by author.

The human brain only extracts visual information during fixations, when the eyes are relatively motionless and are focusing on stimuli (Buscher et al. 2009; Bojko 2013). The Hand Washing, Pit Latrine, and Solar Disinfection KDEs contain erratic fixations signified by the color blue (Figure 23). According to Buscher et al. (2009), there are three main factors that influence the location of fixations: 1) salience of areas within the image; 2) memory and expectations of where to find information; and 3) the desired task and information need. For this research, the salience of areas is based on graphical design with image characteristics that include contrast, color, intensity, edge density, and edge orientation to draw the user to the key constructs of each intervention visualization. Fixations are located at the most salient spots in order to maximize information gain (Buscher et al. 2009). Memory and expectations also play key roles in fixations. Most, if not all, eye-tracking participants had not seen a computer or visualizations similar to the ones used for the research prior to participating in the research. The erratic fixations could explain the visual behaviors of participants scanning the graphic in search of information gain. As aforementioned, the main objective for each design was that a user's attention would be drawn to the key constructs for each intervention. All four intervention KDEs (Figure 23) are well represented in this regard and, therefore, can be considered graphically effective about communicating information.

5.2.4 Visual Learning Assessment

According to Clifford et al. (2014), research that incorporates a mixed methods approach allows for the ability to develop a clearer understanding of a test hypothesis. Learning outcomes found in typical studies were not determined for this research; however, visual learning effectiveness was determined and can be viewed as a novel step in learning assessments. Culturally relevant graphics that attract attention foster working memory and recall leading to an environment that supports learning rather than its impedance (Curran and Doyle 2011).

The knowledge base levels (KBL) of the interventions for Boiling Water, Hand Washing, and Pit Latrine were higher values than the respective visual learning effectiveness (VLE) levels (Table 5). The Solar Disinfection intervention was the only intervention to have a higher value from a KBL of 0.27 to a VLE level of 0.87. It is important to note that KBL and VLE questions were not the same and, therefore, these two categories should only be used in comparison analysis for understanding the pre-knowledge level of individuals and groups. Kernel density estimations for each intervention graphic support the methods and design approach used for this research and quantifies the ROIs for observers. Each intervention graphic had "hot spots' on the key constructs. Graphical effectiveness supports the research objective that visual learning can be used to overcome the challenges of education in low-literacy environments for oral cultures.

5.3 Demographic Visual Learning Effectiveness

Knowledge pre-assessment interviews were recorded and later transcribed in order to determine a baseline knowledge level associated with each individual. Nearly 24 hours of audio interviews were recorded during the pre-knowledge assessment sessions and the post visual learning effectiveness assessments. Responses were assessed using a scoring rubric (Andrade 2005; Jonsson and Svingby 2007; Reddy and Andrade 2010) for correct and incorrect answers. Participant responses were scored 0 for an incorrect answer and 1 for each correct answer (two questions total). The two questions' categories included: 1) participant knowledge on how to conduct the particular intervention, and 2) why it was important (i.e., boiling water to neutralize pathogens; hand washing to clean hands at key junctures, before eating and after defecation to limit contamination of pathogens; pit latrine use as opposed to open defecation in and around waterways to limit non-point source pollution; and solar disinfection for water treatment to neutralize pathogens). Each question score was summed and then divided by the total population for each demographic with 2 the highest score possible, in an effort to determine the pre-knowledge base levels of demographic groups and individuals (Table 6).

Demographic Knowledge Base Levels

Demographic	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
Total People	104	1.34 (67%)	1.95 (98%)	1.55 (78%)	0.27 (14%)
Educated	44	1.70 (85%)	2.00 (100%)	1.72 (86%)	0.23 (12%)
Uneducated	60	1.07 (54%)	1.92 (96%)	1.43 (72%)	0.29 (15%)
14 to 35	57	1.32 (66%)	1.95 (98%)	1.53 (77%)	0.23 (12%)
36 to 75	47	1.36 (68%)	2.00 (100%)	2.00 (100%)	0.33 (17%)
Market	56	1.38 (69%)	1.98 (99%)	1.44 (72%)	0.22 (11%)
Non-Market	48	1.29 (65%)	1.92 (96%)	1.33 (67%)	0.33 (17%)
Songhai	40	1.33 (67%)	1.98 (99%)	1.65 (83%)	0.32 (16%)
Zerma	42	1.43 (72%)	1.95 (98%)	1.52 (76%)	0.21 (11%)

Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 6. Demographic knowledge base levels.

For this research, the education levels of eye-tracking participants included three categories: graduated, some education, and no education (Table 7). The *Graduated* category represents those individuals who graduated high school. Fourteen of the nineteen individuals who graduated high school were village health-care workers. Health care workers included one doctor, three clinic majors, six nurses, one midwife, and three clinic assistants. The *Some Education* category signifies participants who did not graduate high school. This category ranges from individuals who spent only one day in some type of education to those who spent several years. The last education category, *No Education*, represents participants who had never received any formal education. The total number of those who were considered educated was 44. Sixty eye-tracking participants had never received any type of formal education.

Education Levels for Eye-Tracking Participants (104 Participants)

Graduated	Some Education	No Education
19	25	60

Graduated category represents high school graduation and includes 14 Village Health Care Workers (1 Doctor, 3 Majors, 6 Nurses, 1 Midwife, and 3 Clinic Assistants).

Some Education category represents participants who did not graduate high school.

No Education category represents no formal education.

Table 7. Education levels for eye-tracking participants.

Village types in the form of market and non-market were also studied during this research. Market villages tend to have larger population sizes and included five villages. Non-market villages are typically very small in comparison to the market villages and included seven villages. Songhai and Zerma were the two cultural groups with the highest frequency among the nine that were studied in the research (Table 4). The Songhai included 40 individuals and the Zerma cultural group included 42 individuals.

Eye-tracking participants' ages ranged from 14 years to 75 years old. There were 40 age categories represented (Table 8). The median age of participants was 34 years. The 40 age groups were divided in half to provide equal distribution, with 20 age groups for 14-35 and twenty age groups for 36-75. There were 57 participants in the 14-35 group and 47 participants in the 36-75 group. The range for the ages was 61 years. Age groups of the study population included 40 categories (Table 8).

Age Statistics for Eye Tracking Trials (104 Participants)

Age Value (yrs)	14	15	16	17	18	19	20	22	23	24	25	26	27	28	30	31	32	33	34	35
Frequency	1	1	4	3	1	4	3	4	2	4	3	1	2	2	10	2	3	1	2	4

Age Value (yrs)	36	37	38	39	40	42	45	46	47	50	52	55	56	57	58	60	63	67	70	75
Frequency	1	5	2	1	6	2	6	2	3	3	3	1	1	1	2	2	1	1	1	3

Age Value Categories = 40 Range = 61 Median = 34 Mode = 30

Table 8. Age statistics for eye-tracking trials.

Demographic Visual Learning Effectiveness

Demographic	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
Total People	104	1.06 (53%)	1.14 (57%)	1.49 (75%)	0.87 (42%)
Educated	44	1.57 (79%)	1.56 (78%)	1.84 (92%)	1.09 (55%)
Uneducated	60	0.68 (34%)	0.83 (42%)	1.22 (61%)	0.71 (36%)
14 to 35	57	1.11 (56%)	1.30 (65%)	1.54 (77%)	0.93 (47%)
36 to 75	47	1.00 (50%)	0.29 (15%)	1.17 (59%)	0.83 (42%)
Market	56	1.11 (56%)	1.18 (59%)	1.50 (75%)	0.84 (42%)
Non-Market	48	0.98 (49%)	1.02 (51%)	0.17 (8.5%)	0.67 (34%)
Songhai	40	1.13 (57%)	1.14 (57%)	1.51 (76%)	0.78 (39%)
Zerma	42	1.00 (50%)	1.24 (62%)	1.38 (69%)	0.90 (45%)

Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 9. Demographic visual learning effectiveness.

Once the participant concluded the eye-tracking trial, she was immediately given the appropriate post-assessment semi-structured interview questions associated for a WSH visualization. Content was assessed using a scoring rubric (Andrade 2005; Jonsson and Svingby 2007; Reddy and Andrade 2010) for correct and incorrect answers. Participant responses were scored 0 for an incorrect answer and 1 for a correct answer, for a total possible score of 2. Each post-assessment question score was summed in order to determine the visual learning effectiveness and to support the educational materials (Table 9).

Pre-knowledge base levels, visual learning effectiveness levels, and kernel density estimations for each aggregated group (education levels, age groups, village types represented in this research, and cultural groups) were compared and contrasted in order to support further the design approach incorporated in the research and to provide possible insight into the ways in which groups visually learn (Figure 32).

5.3.1 Educated versus Uneducated

Pre-knowledge base levels for educated participants' boiling water, hand washing, and pit latrine results were higher than those determined for the uneducated participants (Table 10). Solar disinfection, however, was higher for the uneducated category. The study's educated population scored a perfect score (2 out of 2) for pre-knowledge of hand washing techniques and protocols. Visual learning effectiveness levels for educated participants were higher in all intervention visualizations, as one might expect. Visual learning effectiveness for the Pit Latrine visualization had the highest score with 1.84 compared to the other intervention visualizations.

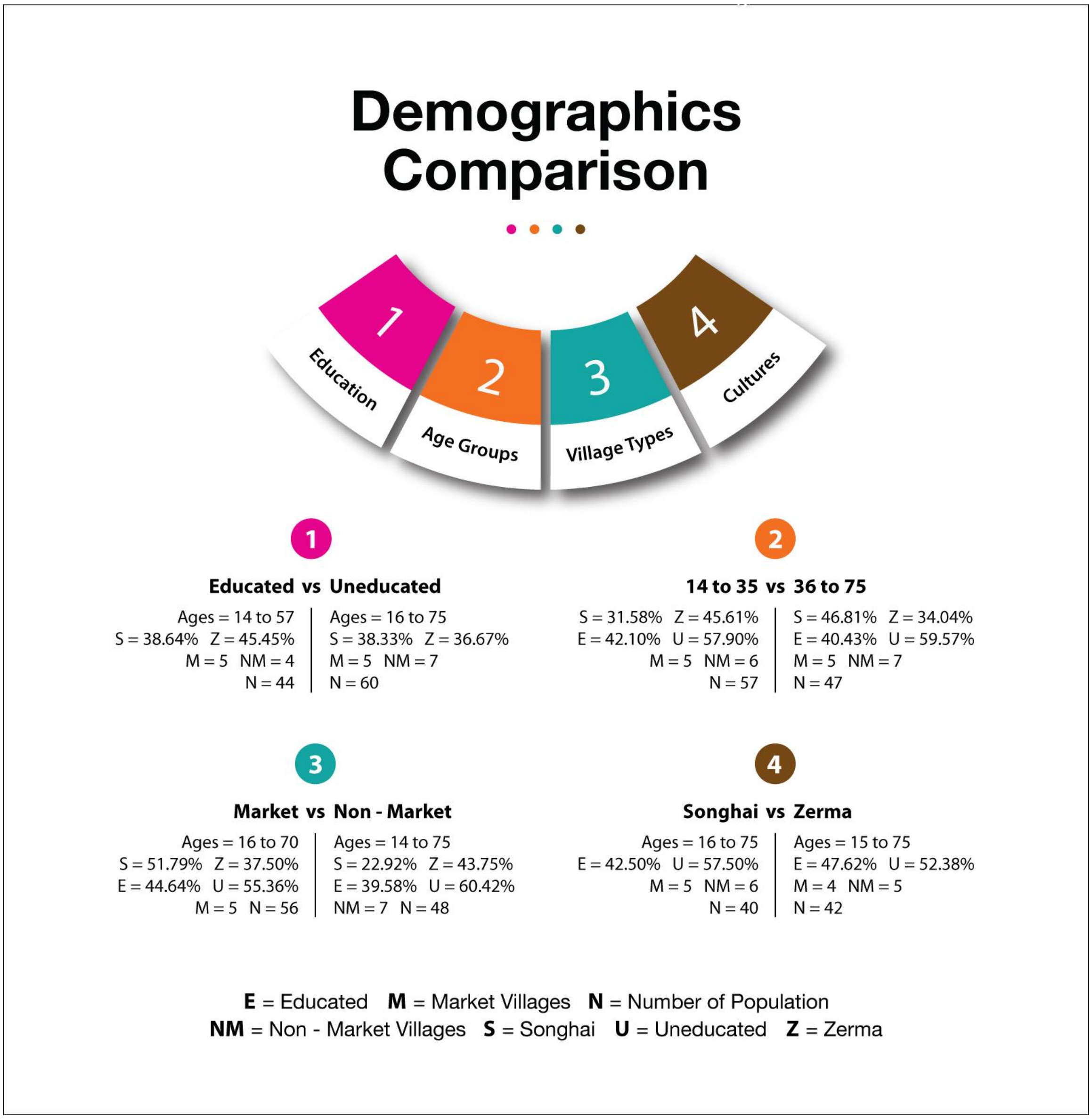

Figure 32. Demographics comparison.
Source: Created by author from eye-tracking trials.

Age ranges for educated participants were 14 to 57 years old. Uneducated ages ranged from 16 to 75 years old (Figure 32). The educated category comprised five market villages and four non-market villages. Uneducated groups were in all 12 villages, comprising five market and seven non-market villages. Kernel density estimations (KDE) were performed on two subgroups of participants (60 uneducated and 44 educated) to identify ROIs from eye-tracking data and, thus, determine the density of aggregated gaze points (Figure 24). Clusters for event occurrences created "hot spots" in space of the point events, which are the areas of the visualization more dense (signified by the color red in the KDE maps). The Educated Boiling Water KDE map reveals participants' ROI to be closest spatially to the intervention graphics. The Uneducated KDE maps for Solar Disinfection and Pit Latrine tend to be more focused on the graphics than their respective Educated KDE maps. All KDE maps (Figure 24) revealed similar "hot spots" for their respective interventions except for the Boiling Water KDE maps. A possible conclusion for the Uneducated Boiling Water KDE map having spatially different aggregated gaze points could be that participants are scanning the graphic in search of information.

Educated Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	44	1.70 (85%)	2.00 (100%)	1.72 (86%)	0.23 (12%)
VLE	44	1.57 (79%)	1.56 (78%)	1.84 (92%)	1.09 (55%)

Uneducated Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	60	1.07 (54%)	1.92 (96%)	1.43 (72%)	0.29 (15%)
VLE	60	0.68 (34%)	0.83 (42%)	1.22 (61%)	0.71 (36%)

KBL = Knowledge Base Level VLE = Visual Learning Effectiveness Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 10. Educated population and uneducated population qualitative measurements for eye tracking trials.

5.3.2. Ages 14 to 35 versus Ages 36 to 75

The age group of 14 to 35 years had 57 participants and the age group of 36 to 75 years had 47 participants (Figure 32). The younger age group of 14 to 35 years had the highest VLEs for all interventions studied compared to the 36 to 75 age group (Table 11). The 36 to 75 age group had a perfect KBL scores for Hand Washing and Pit Latrine; however, the Hand Washing VLE was the lowest measured for all groups studied with a score of 0.29 (Table 12). This could be due to an educational advantage the younger population has over the older population, as international funding has provided more educational opportunities for learning. Additionally, the younger population could be considered more informally educated than the older population, as formal uneducated levels for the age group 14 to 35 are still high at 58% of the total population. Informal education, or lifelong learning, is the process by which individuals acquire skills and knowledge from daily experience (Marsick and Watkins 2001; Enos et al. 2003; Kim and McLean 2014). Influences and educational resources from an individual's environment are key to learning climates and cultures, which nurture opportunities that promote interest, experience, and confidence. According to Marsick and Watkins (2001), informal learning occurs in an individual, in interactions among individuals, in organizations, and within the broader environment. The low education levels found in the Republic of Niger forces individuals to learn outside the classroom. The Boiling Water KDE map for the 14 to 35 age group (Figure 24) contained a narrow band of aggregated gaze points compared to the 36 to 75 age group. Participants for the younger age group may have not needed as much time to scan as long as information was gained quicker than the older population age group.

14 to 35 Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	57	1.32 (66%)	1.95 (98%)	1.53 (77%)	0.23 (12%)
VLE	57	1.11 (56%)	1.30 (65%)	1.54 (77%)	0.93 (47%)

36 to 75 Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	47	1.36 (68%)	2.00 (100%)	2.00 (100%)	0.33 (17%)
VLE	47	1.00 (50%)	0.29 (15%)	1.17 (59%)	0.83 (42%)

KBL = Knowledge Base Level VLE = Visual Learning Effectiveness Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 11. 14 to 35 population versus 36 to 75 population qualitative measurements for eye tracking trials. Source: Created by author from eye-tracking trials.

5.3.3 Market Villages versus Non-Market Villages

Market villages had a larger population of the Songhai cultural groups at 51.79% of the total population, compared to only 22.92% in non-market villages (Figure 32). Fifty-six eye-tracking participants were from market villages and 48 were from non-market villages. All Market Villages study populations had higher VLEs than their respective Non-Market VLEs. The Market Villages had populations that ranged from 2,000 to 17,000 inhabitants while Non-Market Villages had populations that ranged from 150 people to 1,900 people. Larger populations found in market villages have more informal learning opportunities for inhabitants. Markets are found along the Niger River where the transfer of knowledge, goods, and services from other regions fosters informal learning interactions among individuals. The Pit Latrine Non-Market Village VLE is the lowest level found for all groups studied at 0.17 (Table 12).

Market Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	56	1.38 (69%)	1.98 (99%)	1.44 (72%)	0.22 (11%)
VLE	56	1.11 (56%)	1.18 (59%)	1.50 (75%)	0.84 (42%)

Non-Market Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	48	1.29 (65%)	1.92 (96%)	1.33 (67%)	0.33 (17%)
VLE	48	0.98 (49%)	1.02 (51%)	0.17 (8.5%)	0.67 (34%)

KBL = Knowledge Base Level VLE = Visual Learning Effectiveness Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 12. Market population versus non-market population qualitative measurements foe eye tracking trials.

The high cost of building a pit latrine in the most rural areas of Niger (non-market villages) could contribute to the low Pit Latrine VLE, as a pit latrine could be an abstract concept similar to solar disinfection. From the qualitative interviews, it was determined that building a pit latrine costs US$100 on average. With nearly 90% of the population of Niger in multidimensional poverty (UNDP 2014), priorities dictate daily human survival over proper waste management. The largest uneducated population found among the groups studied belonged to the Non-Market Villages group that had 60.42% of the total population (Figure 32). The Non-Market Villages' KDE maps for Boiling Water, Hand Washing, and Pit Latrine do not have as large of scan patterns as the Market Villages' KDE maps (Figure 26). The Market Village Pit Latrine KDE map has two distinct (signified by the color red) aggregated areas where the boy who is using the pit latrine compared to only one larger area in the Non-Market Pit Latrine KDE map.

5.3.4 Songhai versus Zerma

The highest frequency for the cultural groups belonged to Zerma with 42 individuals. Songhai was the second highest frequency with 40 individuals (Table 4). The two cultural groups with the highest frequencies were used for the cultural groups' demographic analysis. The Zerma KBL for solar disinfection was the lowest determined for all groups studied. The Songhai cultural group population was 51.79% of the total sample population compared in market villages to only 22.92% in the non-market villages. As discussed earlier, inhabitants in market villages have more opportunities for informal learning than their non-market village counterparts. The KDE maps for both cultural groups are similar to one another when comparing the Boiling Water, Pit Latrine, and Solar Disinfection (Figure 27). The Hand Washing KDE maps, however, do show different gaze patterns with the Zerma KDE map displaying more erratic scan patterns. The Songhai VLE was higher for Boiling Water and Pit Latrine, while the Zerma VLE for Hand Washing and Solar Disinfection was higher (Table 13).

5.4 Spatial Autocorrelation Analyses

Spatial statistical analyses were performed on the Solar Disinfection visualization to further examine the graphical effectiveness. The solar disinfection visualization was chosen due to the lowest pre-knowledge of the intervention (Table 5) and the abstractness that surrounded the concept among the target populations studied. ArcGIS was unable to perform the statistical analyses due to the large dataset for the fixation point features. To solve this problem, the study area was divided into three sections, which focused on the steps for solar disinfection (Figure 33).

Songhai Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	40	1.33 (67%)	1.98 (99%)	1.65 (83%)	0.32 (16%)
VLE	40	1.13 (57%)	1.14 (57%)	1.51 (76%)	0.78 (39%)

Zerma Population Qualitative Measurements for Eye Tracking Trials

Category	n	Boiling Water	Hand Washing	Pit Latrine	Solar Disinfection
KBL	42	1.43 (72%)	1.95 (98%)	1.52 (76%)	0.21 (11%)
VLE	42	1.00 (50%)	1.24 (62%)	1.38 (69%)	0.90 (45%)

KBL = Knowledge Base Level VLE = Visual Learning Effectiveness Levels obtained using a Scoring Rubric with 2.00 being the highest score possible.

Source: Data created by author from eye-tracking trials.

Table 13. Songhai population versus Zerma population qualitative measurements for eye tracking trials. Source: Created by author from eye-tracking trials.

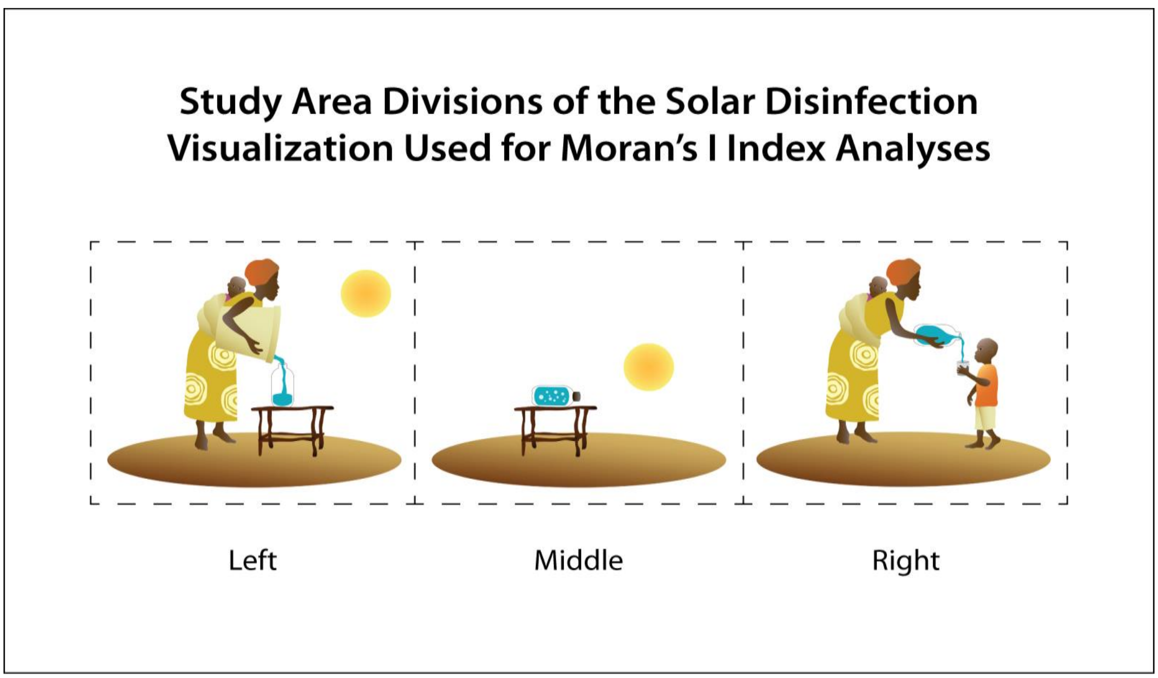

Figure 33. Study area divisions of the solar disinfection visualization used for Moran's I index analyses. Source: Created by author from eye-tracking trials.

Spatial autocorrelation analyses, in the form of Global Moran's I, and Local Moran's I, and a point pattern analysis, Nearest Neighbor, revealed Z-scores and Indexes that further support the graphical effectiveness of the visualizations with clustering of the fixation point features (Table 14). The Inverse Distance function for conceptualization and Euclidean function for distance method were used for each of the autocorrelation analyses. The Global Moran's I index for each study area division is: left study area at 0.026295 (p-value = 0.000), middle study area at 0.063063 (p-value = 0.000), and right study area at 0.044850 (p-value = 0.000). Given the Z-score values, there is less than 1% likelihood that the observed clustered patterns could be the result of random chance.

Spatial Autocorrelation Analyses for Solar Disinfection Visualization

Global Moran's I Index

Study Area	GMI	Z-score	P value
Left	0.026295	28.828144	0.000
Middle	0.063063	66.300161	0.000
Right	0.044850	41.424937	0.000

Given the Z-score values of the Left, Middle, and Right study areas, there is less than 1% likelihood that the observed clustered patterns could be the result of random chance.

GMI = Global Moran's I Index

Nearest Neighbor Index

NNI	Z-score	P value
0.344190	-212.196021	0.000

Given the Z-score value, there is less than 1% likelihood that the observed clustered pattern could be the result of random chance.

NNI = Nearest Neighbor Index

Table 14. Spatial Autocorrelation Analyses for Solar Disinfection Visualization.
Source: Created by author from eye-tracking trials.

The Global Moran's I analysis is an inferential statistic, where the results of the analysis are interpreted within the context of its null hypothesis based on feature locations and attribute values (Wade and Sommer 2006; Xie and Yan 2008; ESRI 2015). Global Moran's I calculates the spatial autocorrelation based on both point feature locations and their attribute values within the study area (i.e., global). This analysis evaluates whether the spatial pattern of attribute values (or time, in this case) is clustered, dispersed, or random. A positive Moran's I index value indicates a tendency towards clustering (or nearby feature attribute values are similar), while a negative Moran's I index value indicates a tendency towards dispersion (or nearby feature attribute values are dissimilar). The Global Moran's Index for each of the study area divisions indicates the patterns for the fixation points of the solar disinfection visualization are clustered (Table 14). In addition, the low p-values combined with the high positive values for the Z-scores for each study area division are statistically significant and further support the clustered patterns of the fixation points and allow the rejection of the null hypothesis. The Z-score for the Global Moran's I statistic is based on the randomization null hypothesis calculation, which states that the attribute being analyzed is randomly distributed among the features in the study area (Wade and Sommer 2006; Xie and Yan 2008; ESRI 2015).

To examine the Global Moran's I result further, the Anselin Local Moran's I (or Local Indicators of Spatial Association (LISA)) was used in ArcGIS to determine if spatial autocorrelation exists at the local level (or how similar, or dissimilar, each individual feature's value is to its surrounding features' values). The spatial association map for the solar disinfection visualization reveals patterns for the fixation times with regard to High-High (HH) attribute value clusters paired with Low-High (LH) attribute value clusters, and Low-Low (LL) attribute value clusters paired with High-Low (HL) clusters (Figure 34). A High-High point refers to it being similar to surrounding points, in that they all have a high value of fixation time. These areas are hot-spots (black color) and in High-Low areas (orange color) they represent an outlier where a high value of fixation time rates are surrounded primarily by low fixation time values. The cluster/outlier type distinguishes between a statistically significant (0.05 level or p-value

< 0.05) cluster of high values (High-High: black color), cluster of low values (Low-Low: blue color), outliers in which a high value is surrounded primarily by low values (High-Low: orange color), and outliers in which a low value is surrounded primarily by high values (Low-High: red color). The High-High clusters (Figure 34) are located near the key constructs in the solar disinfection visualization (Figure 31), which further supports the graphical effectiveness of the visualization and use of eye-tracking to quantify its evaluation.

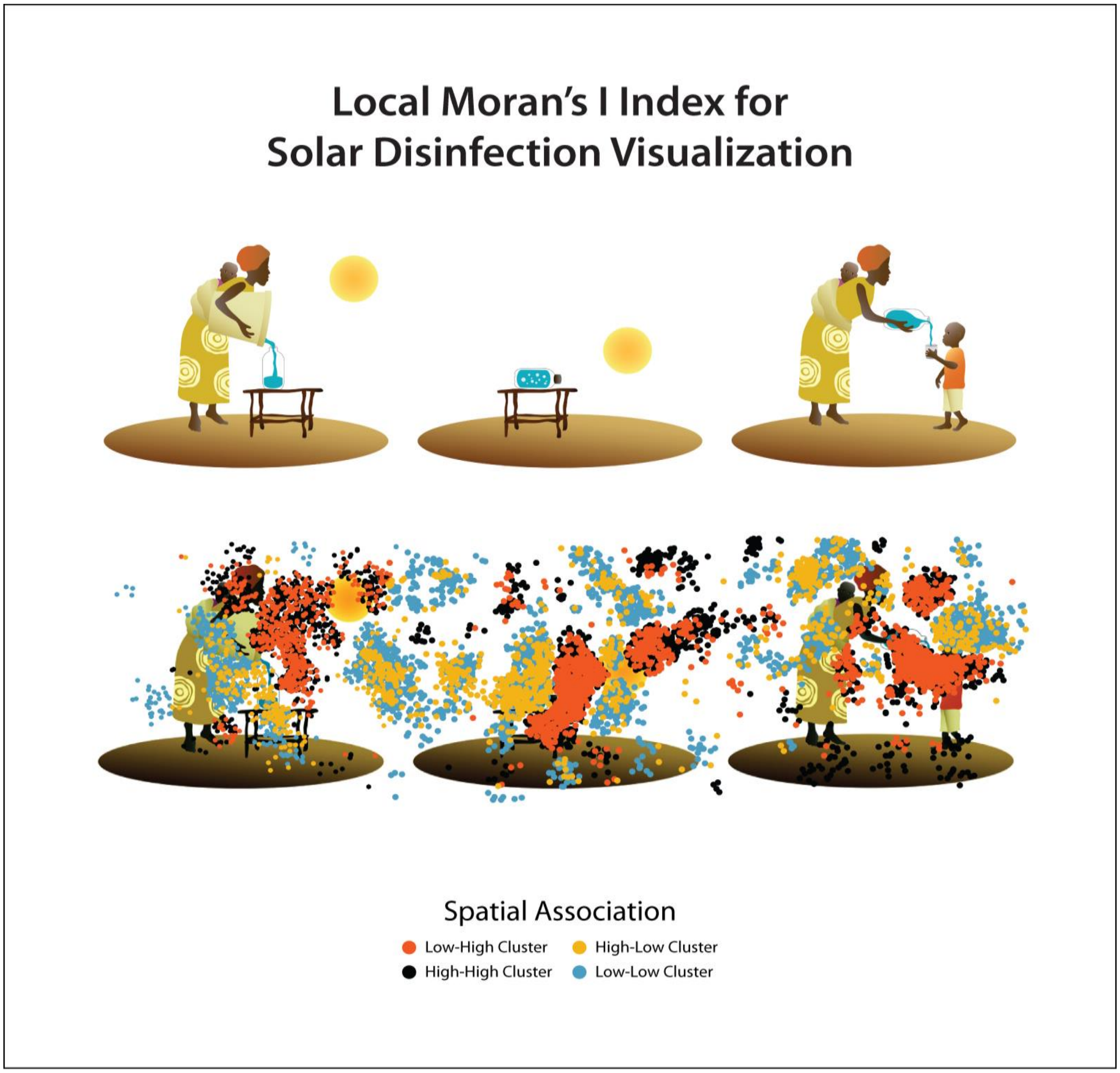

Figure 34. Local Moran's I index for solar disinfection visualization.
Source: Created by author from eye-tracking trials.

The Nearest Neighbor Index for the solar disinfection visualization was 0.344190 (p-value = 0.000) (Table 14). Fixation points from the Local Moran's I that were not significant were left out of the nearest neighbor analysis. The Average Nearest Neighbor analysis measures the distance between each feature's centroid location and its nearest neighbor's centroid location within a study area. If the observed average distance is less than the expected average for a hypothetical random distribution, then the spatial distribution of the point features being analyzed is considered clustered. If the observed average distance is greater than a hypothetical random distribution, the features are considered dispersed (Wade and Sommer 2006; Xie and Yan 2008; ESRI 2015). The Nearest Neighbor Index value for the solar disinfection indicates the fixation points are clustered. Nearest-neighbor distance focuses on the relationship structure of point events to determine spatial point patterns (Xie and Yan 2008).

The cluster/outlier analysis of the Local Moran's I was studied further by using proximity (location) as well as the attribute values (HH, LL, LH, and HL) of clustered groups. Eleven group clusters were determined based on the left study area division of the solar disinfection visualization. These clustered groups were analyzed for the spatial mean (green circle) and the spatial standard distance (green ellipse) and can be viewed in Figure 35.

By combining results from this thesis research with spatial autocorrelation analyses, robust possibilities could emerge that help determine cognitive thinking processes. Areas of study, such as right brain/left brain dominance and peripheral vision dynamics, could provide a new understanding for the ways in which diverse cultural populations visually process and learn from spatially autocorrelated eye-tracking analyses. Spatial relationships of the key constructs for each of the visualizations used in the West Africa case study suggest people do fixate on the areas designed for graphical effectiveness. By combining attribute values and proximity analyses, novel research models for eye-tracking and cognitive thinking could be used for the creation of advanced learning materials.

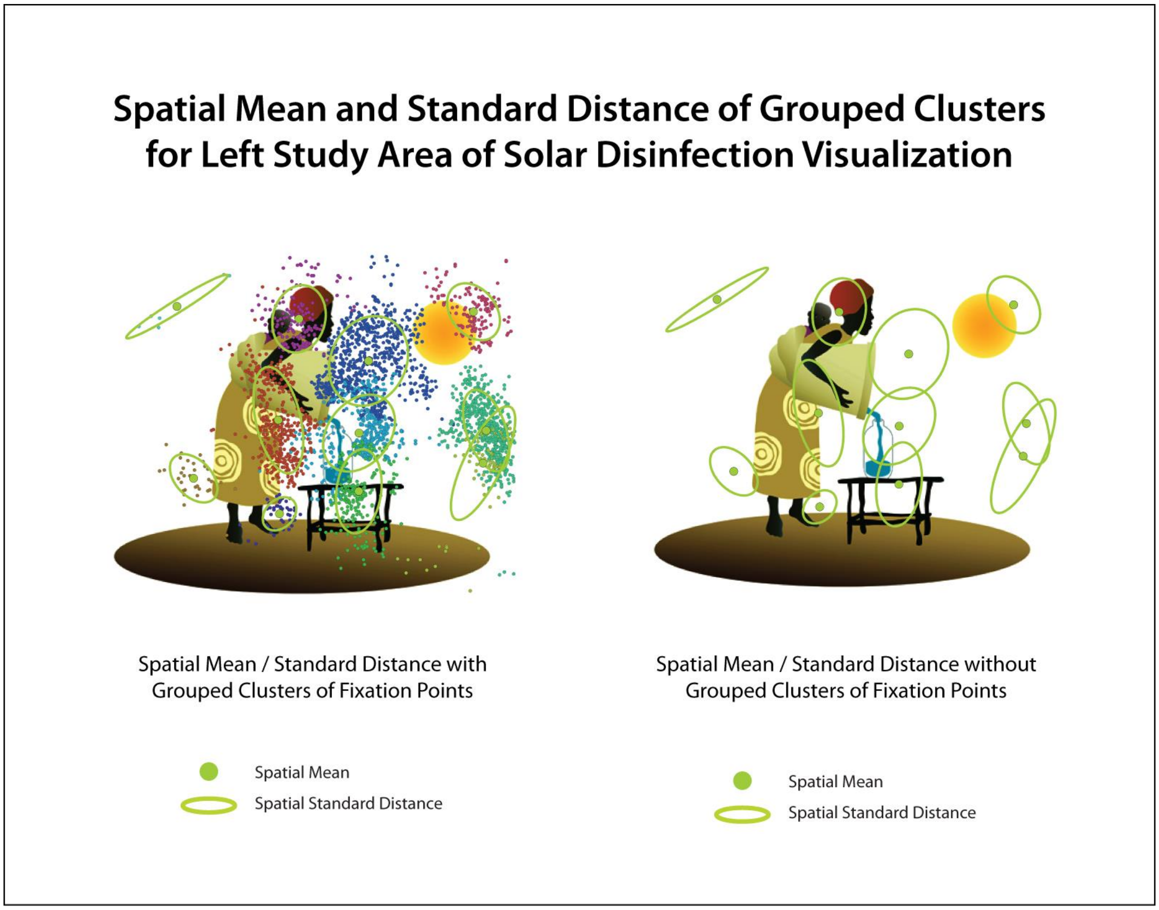

Figure 35. Spatial mean and standard distance of grouped clusters for left study area of solar disinfection visualization. Source: Created by author from eye-tracking trials.

Chapter 6: Conclusion

Using Niger as a case study, this research proposed that visual communication can be used to overcome cultural, societal, and educational barriers for the prevention of diseases associated with water, sanitation, and hygiene. Imagery used for health communication purposes must be educationally accurate and designed to entice and engage, all of which will reinforce the desired message or theme. This research considered the uniqueness of the cultural and physical geography of West Africa, and the informal education environment in rural villages. Visual learning design factors were incorporated into water literacy materials in order to study ways in which cultural and societal barriers can be overcome through culture- and gender-appropriate graphics designed to foster visual storytelling.

Women were targeted as the study population, as they are the primary water fetchers and handlers in sub-Saharan Africa. Kernel density estimation (KDE) analyses were performed in an effort to compare and contrast the KDE of varying education levels, age groups, ethnic groups, and village types. This is one of (and perhaps) the first studies of its kind to investigate effective visual learning design with eye-tracking in rural villages of West Africa. Eye-tracking technology and GIS tools were used for quantification of the visual design characteristics. Research was conducted in 23 villages along the Niger River, and included 510 interviews, 693 focus group participants, nine different cultural groups, over 30 hours of audio interviews, and 464 eye-tracking trials. Tobii X2-60 eye-tracking equipment was used in bush maternity wards, medicinal depositories, and mud-brick homes. Eye-tracking data were imported into ArcGIS, where KDE analyses were performed.

The design of educational visualizations to promote scientific learning, in the form of health interventions and disease prevention, should be created with the intent to be accurate and memorable. Concepts that are remembered should lead to increased understanding. In order for visualization to be effective, it should be designed to be applicable for its particular education scenario. For the design of the education graphics used in this research, four distinct categories were vital to their creation: 1) graphical design, 2) scientifically accurate, 3) end users for target population, and 4) learning assessments (Block et al. 2012). The inclusion of these categories promoted interdisciplinary collaboration, but also gave rise to design challenges to satisfy each categorical need. The design criteria required solutions that fostered deep engagement.

Visual learning assets and barriers were determined from the semi-structured interview sessions, which provided feedback and the consultative factor necessary for proper design and effectiveness (Mansoor and Dowse 2004; Curtis et al. 2005). Assets included aesthetics that captured attention (Arbuckle 2004), the use of culturally relevant environments (i.e., objects, clothing, landscapes, and people), gender-appropriate images (Morris and Stillwell 2003; Carstens 2004), visual storytelling techniques that provoked emotion (Curtis et al. 2011; Duarte 2008), and storyboard pacing of the intervention steps (Duarte 2013). Visual learning barriers were documented, which led to the creation of new visualization designs in order to limit the barriers' ability to impede learning.

Graphical effectiveness of the intervention visualizations was measured in the form of Visual Learning Effectiveness. The Visual Learning Effectiveness for the Boiling Water, Hand Washing, Pit Latrine, and Solar Disinfection strategies support the design approach and methods incorporated. Graphic designs used in informal learning campaigns are different from those in formal settings. These types of visualizations are used in public spaces with diverse users who have a wide range of experiences and backgrounds (Block et al. 2012). Studying the nine different cultural groups for this research, with varying education levels and age groups, provided the foundation for diversity. Educational visualizations used in informal learning environments must strike a balance between enticement and validity (Block et al. 2012). The intervention designs for this research prioritized aesthetics in order to attract the users, and provided visual clarity so participants could recognize visual components and understand their meaning in the context of the intervention being utilized. Qualitative interviews revealed participants' attention was captured by the aesthetics, and provoked emotion. The graphical design of the visualizations promoted interaction to guide the users systematically in the learning and discovery process (Block et al. 2012). Comparing the demographics of the eye-tracking study's population provided a thorough analysis of education levels, age groups, village types, and cultural groups represented in this research, and further supported the design approach incorporated.

Visualizations that are used for scientific purposes in informal learning environments should use designs that leave a strong aesthetic impact on the viewer's perception of the underlying education concepts. Efficiency in terms of visuals that are emotionally engaging can play a key role in a learner's understanding. The interplay of visual interaction and visualization should be at the center of a design for systematic learning applications in order to engage and guide the learners (Block et al. 2012). The KDE maps for each aggregated study group revealed users focused on the key constructs and components for the Boiling Water, Hand Washing, Pit Latrine, and Solar Disinfection intervention graphics.

Results from this research suggest that visual communication can be used to overcome low education and cultural barriers for waterborne disease prevention. Using an adaptive visual learning approach for the research methods provided a creative alternative to conventional water education materials, as most do not consider mother tongue and low literacy. By using visual communication, in particular the methods in this research, a novel way is revealed to understand how socially disadvantaged populations visually process information. With a projected increase of 1.3 billion people between now and 2050, Africa will add more to the global population than any other world region (Haub and Kaneda 2013). Current problems will coalesce and become even more critical if changes are not implemented both now and in the future. Overcoming the desperate need for improved water-focused educational materials can help address the cycle of sickness and death within sub-Saharan Africa, the region's poorest area, where a child dies every fifteen seconds from diarrhea (George 2009; Bizzarri et al. 2011), and in other disadvantaged populations around the world. Visual communication should not be viewed as a panacea, but as a strong foundation for new ways of approaching education in cultures that are in desperate need of alternative methods for health and survival.

Chapter 7: References

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Appendix: Kernel Density Estimations

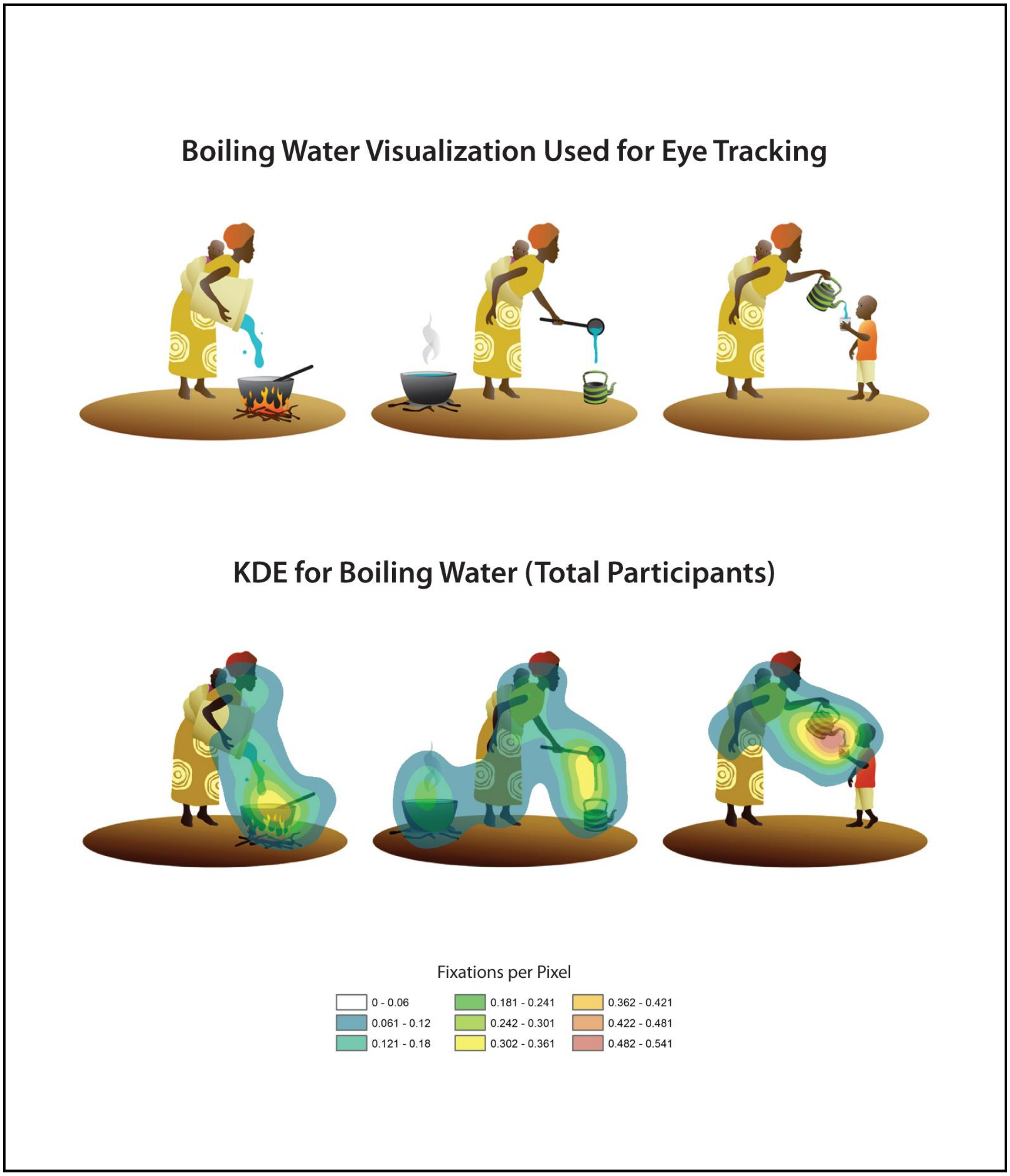

Figure A1. Kernel density estimation for Boiling Water visualization (Total Participants). Source: created by author from eye-tracking trials.

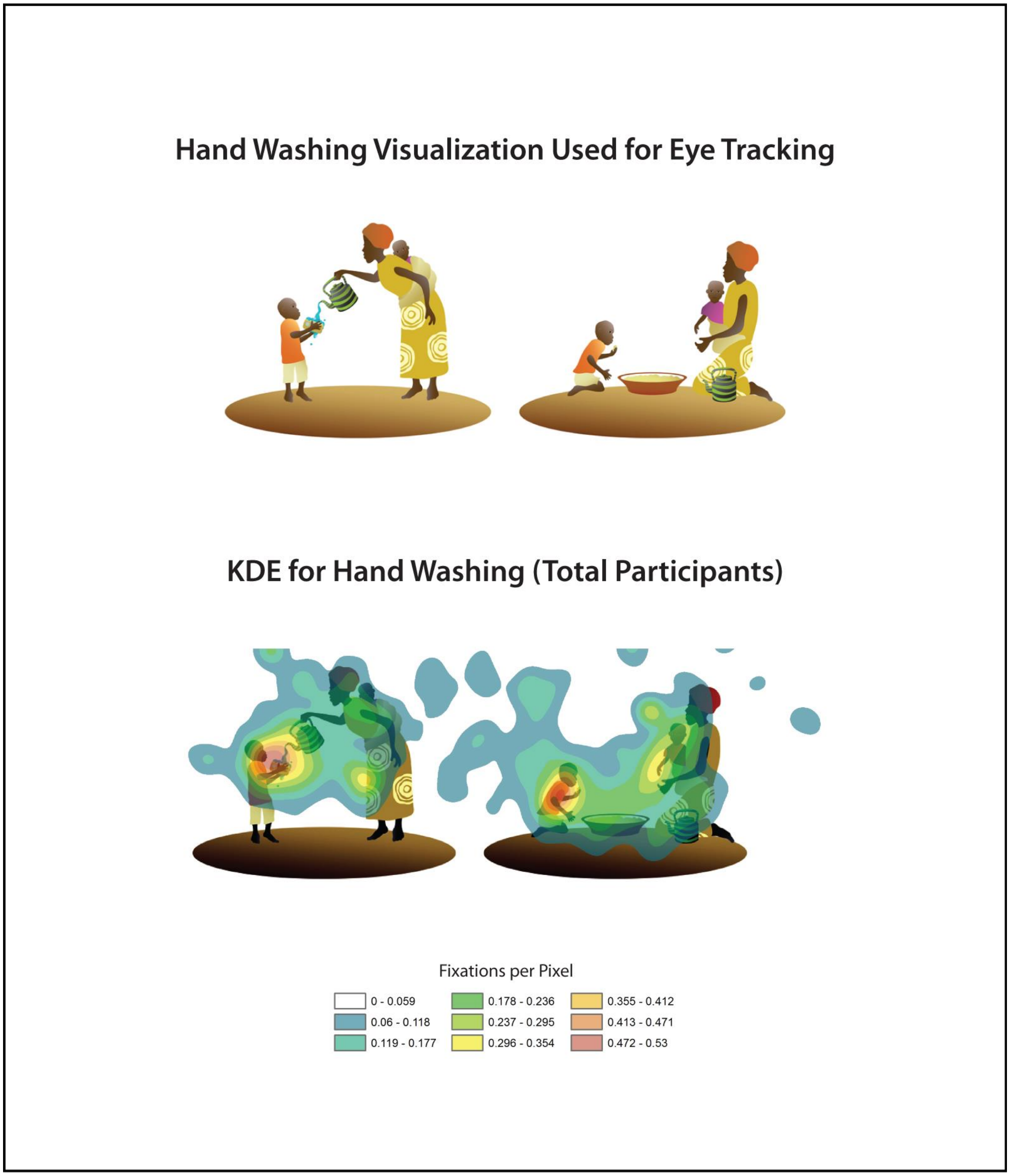

Figure A2. Kernel density estimation for Hand Washing visualization (Total Participants). Source: created by author from eye-tracking trials.

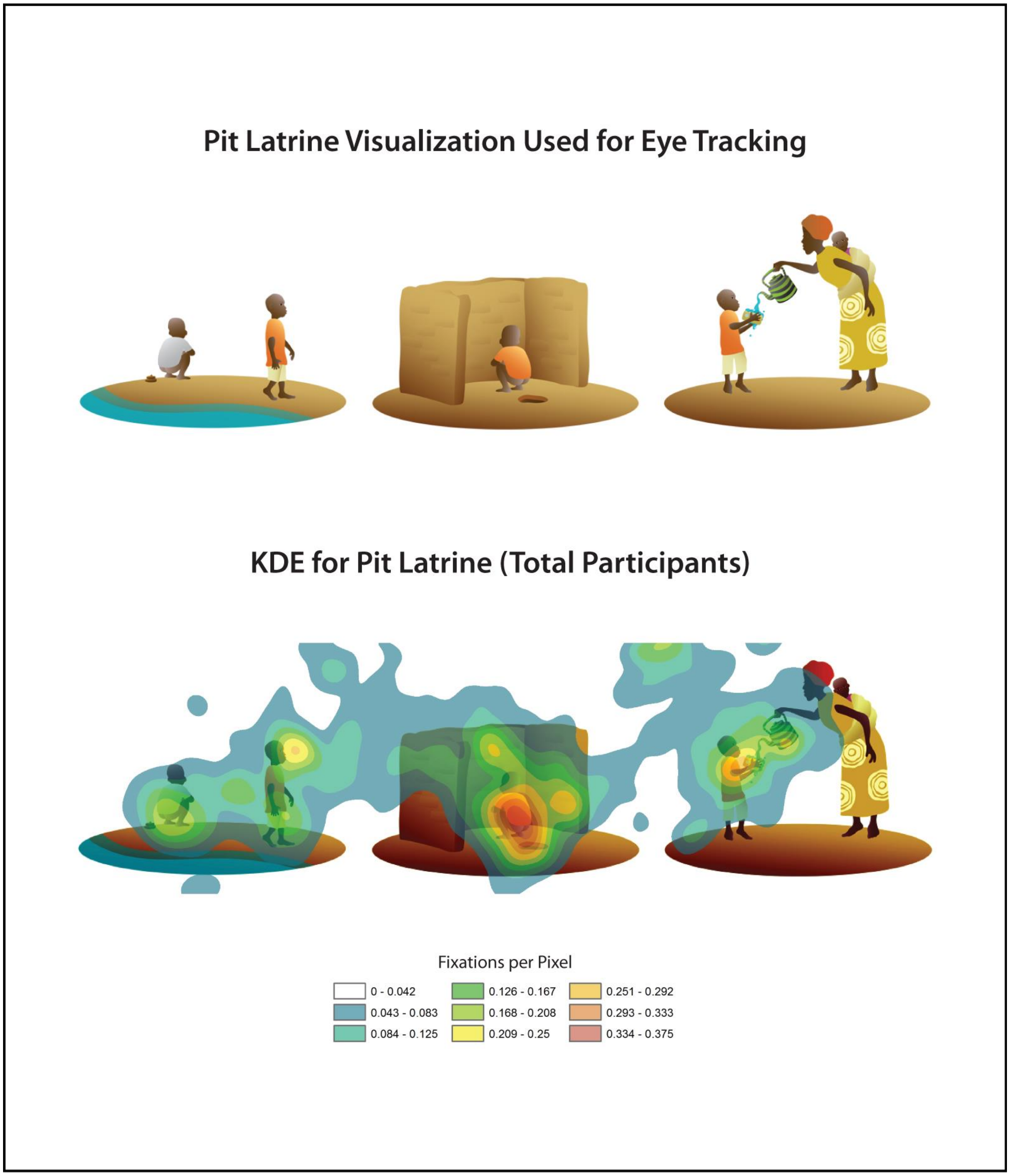

Figure A3. Kernel density estimation for Pit Latrine visualization (Total Participants).
Source: created by author from eye-tracking trials.

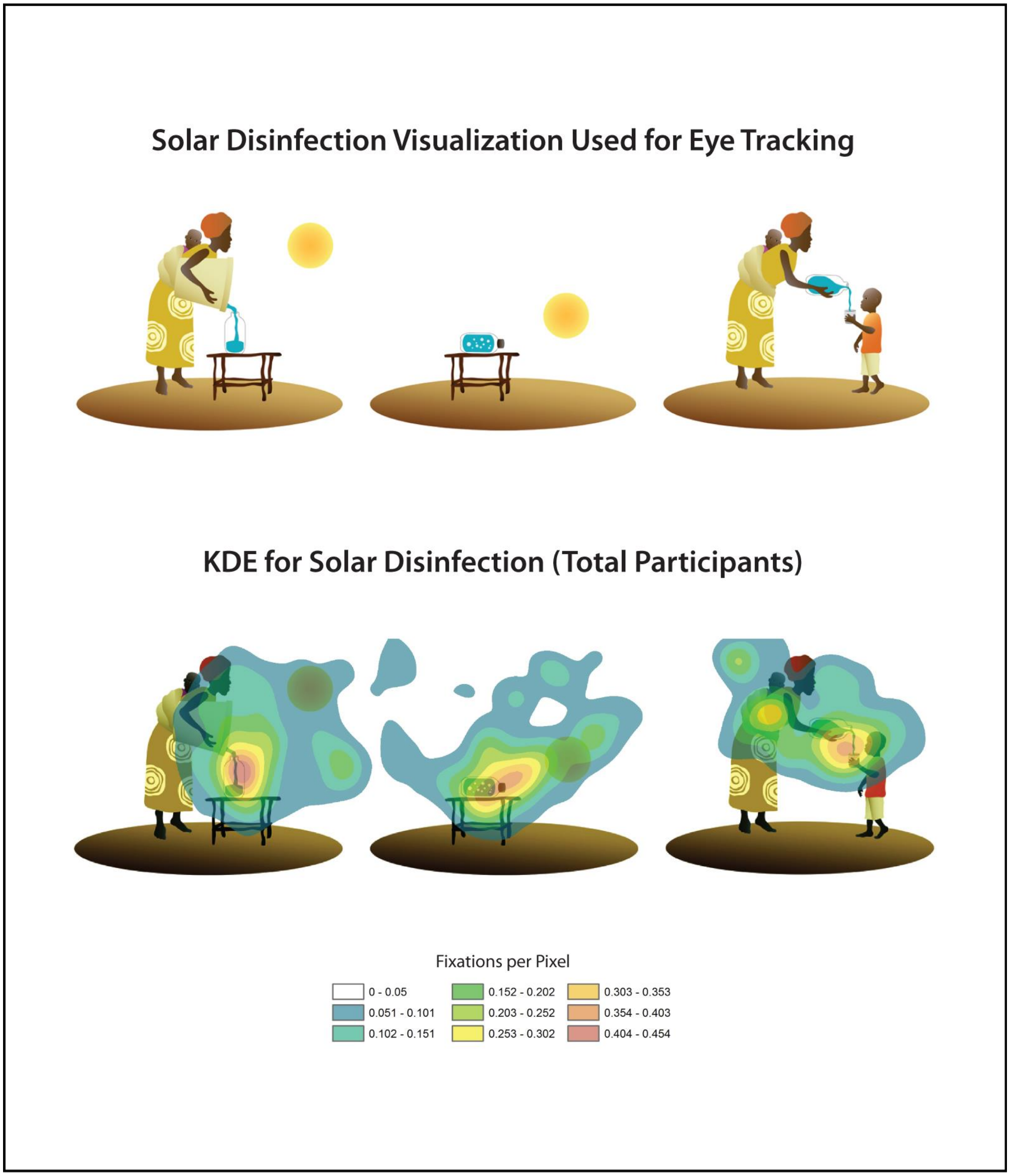

Figure A4. Kernel density estimation for Solar Disinfection visualization (Total Participants). Source: created by author from eye-tracking trials.

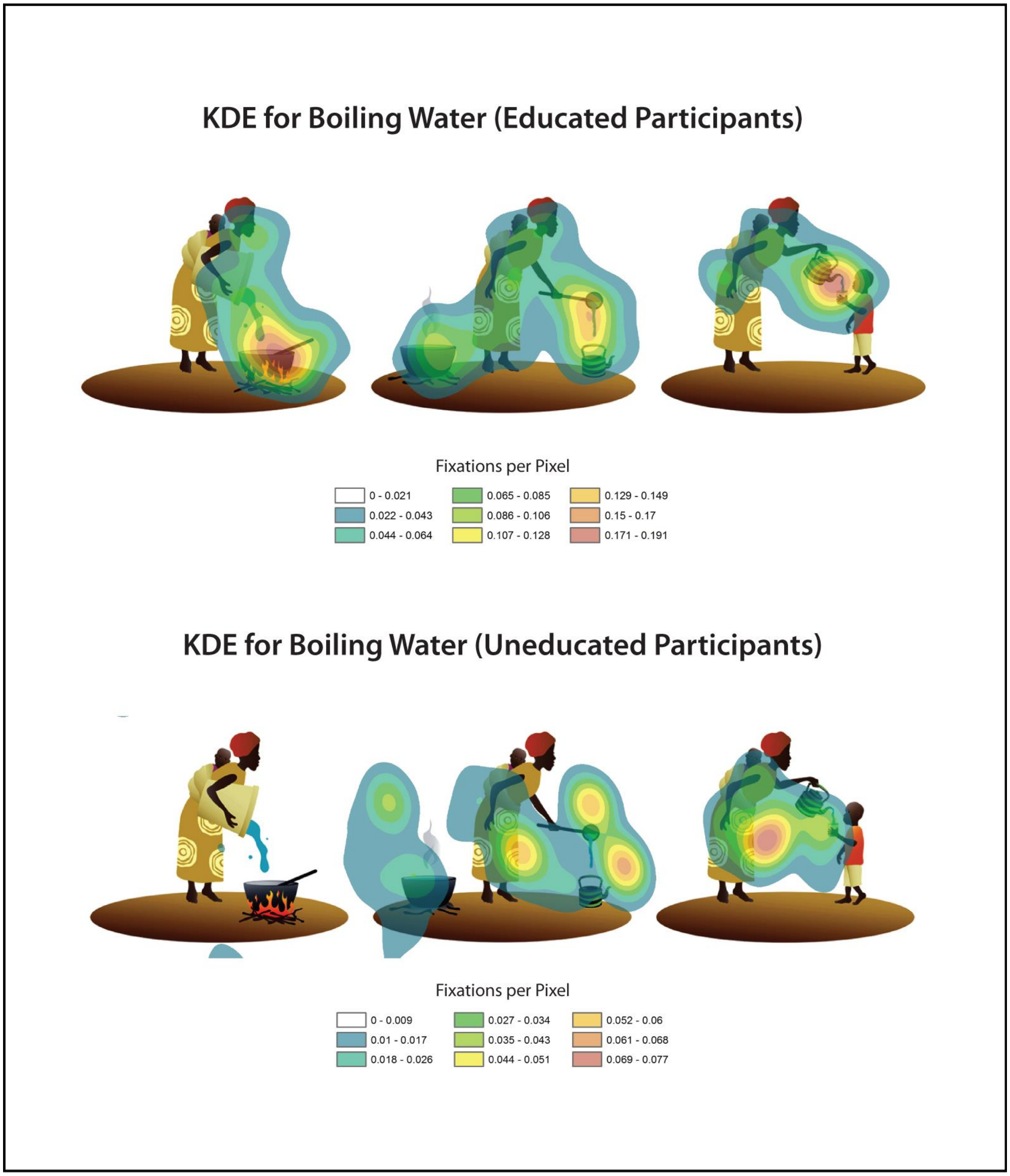

Figure A5. Kernel density estimation for Educated versus Uneducated participants (Boiling Water Visualization). Source: created by author from eye-tracking trials.

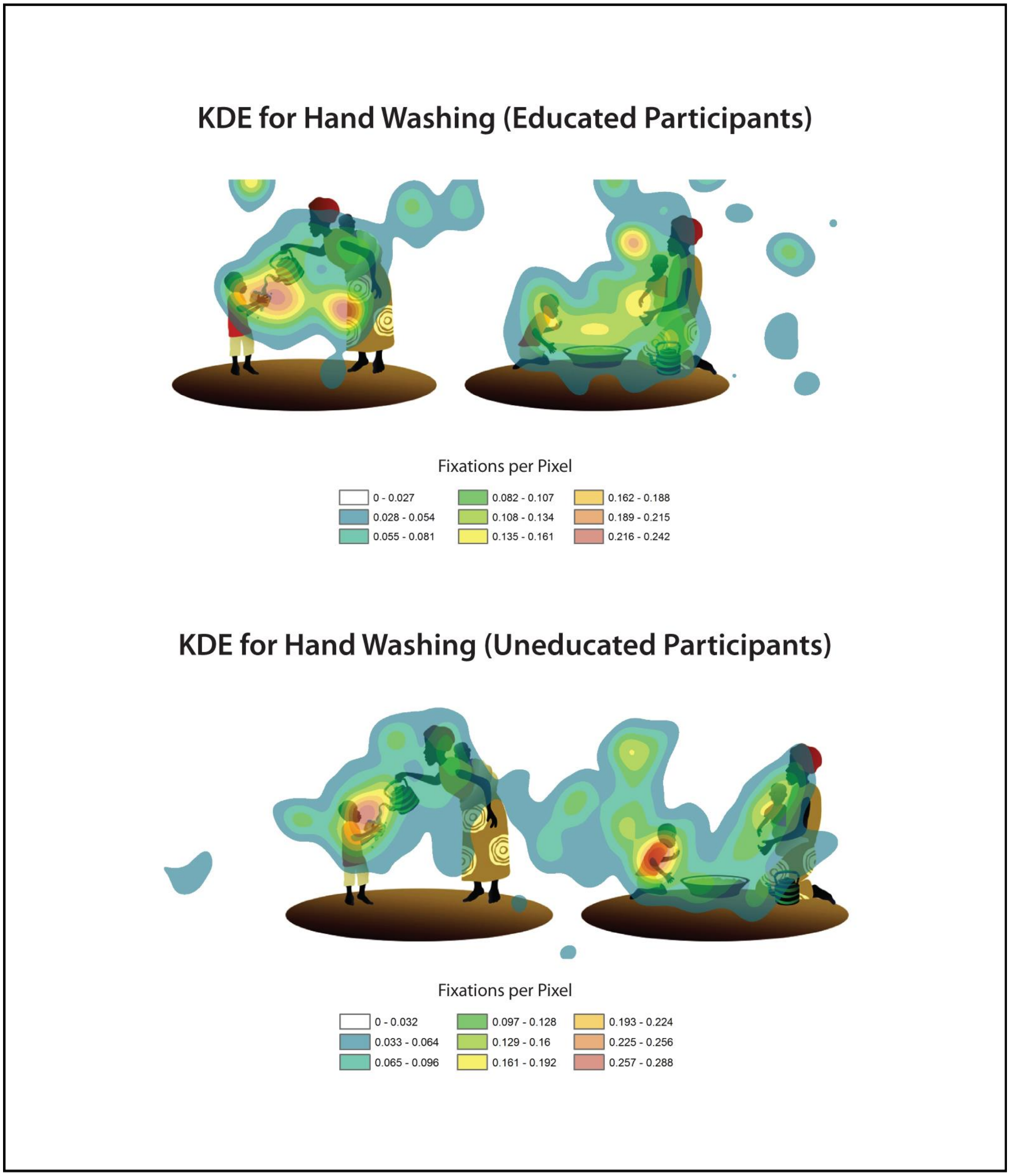

Figure A6. Kernel density estimation for Educated versus Uneducated participants (Hand Washing Visualization). Source: created by author from eye-tracking trials.

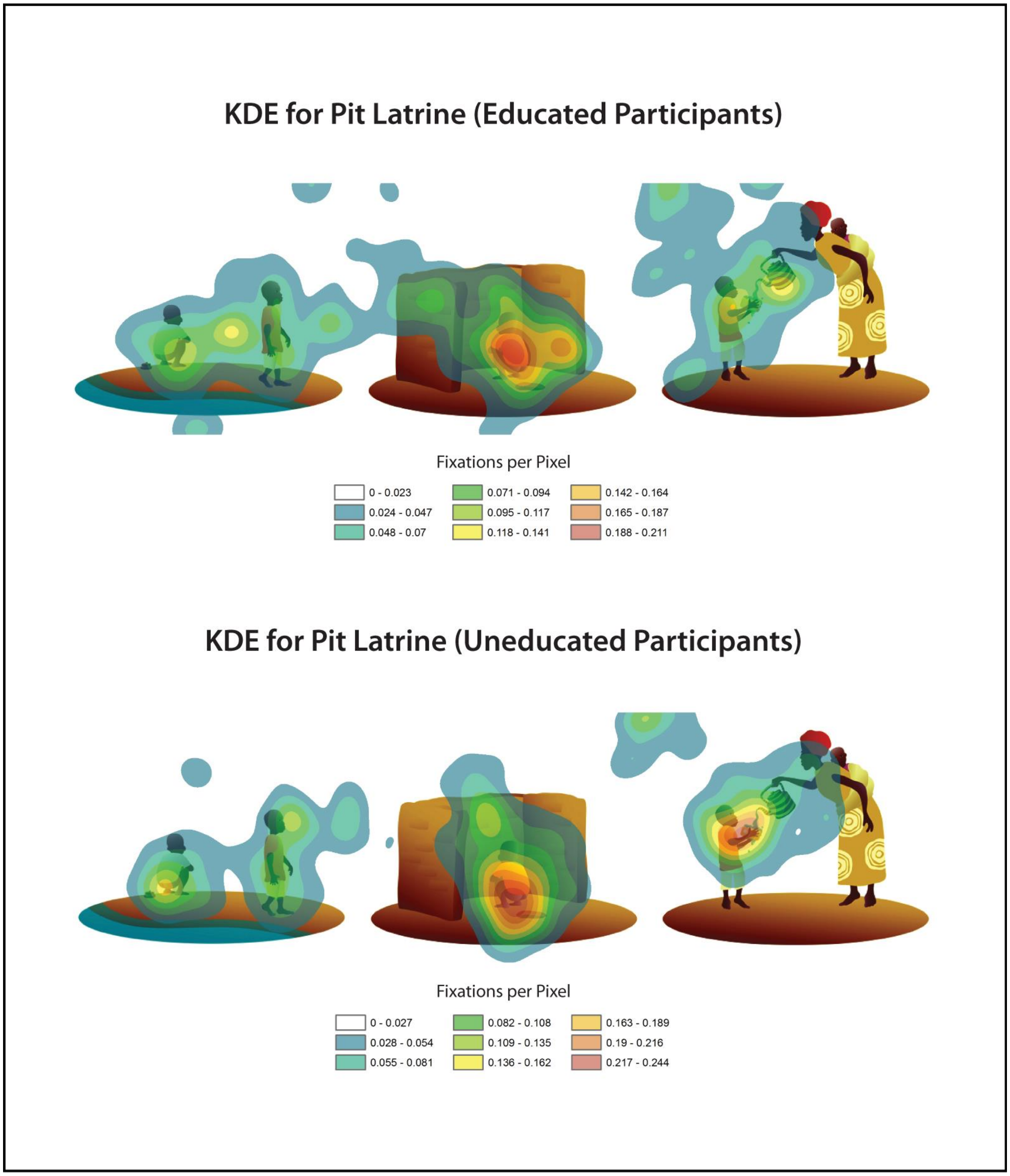

Figure A7. Kernel density estimation for Educated versus Uneducated participants (Pit Latrine Visualization). Source: created by author from eye-tracking trials.

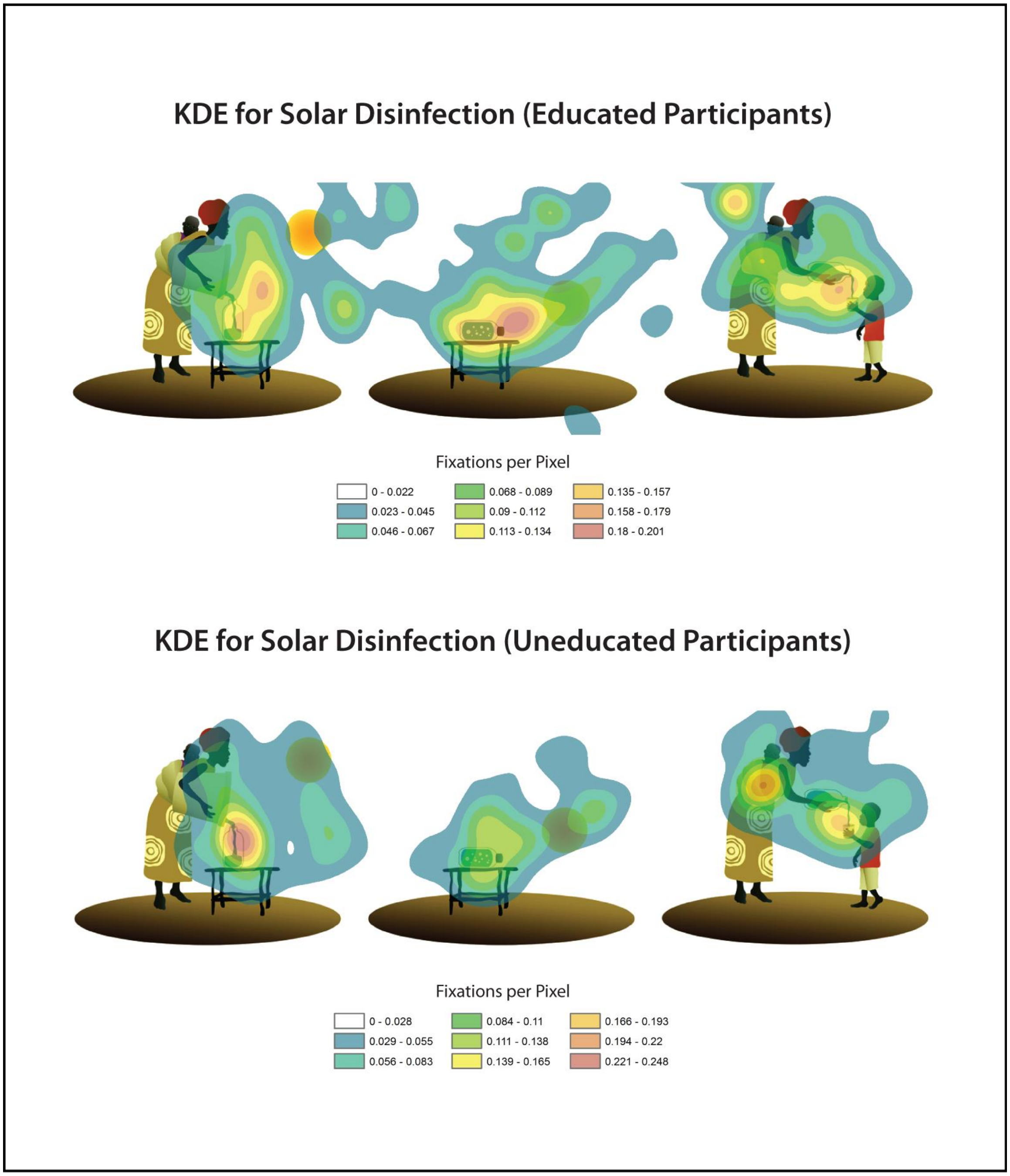

Figure A8. Kernel density estimation for Educated versus Uneducated participants (Solar Disinfection Visualization). Source: created by author from eye-tracking trials.

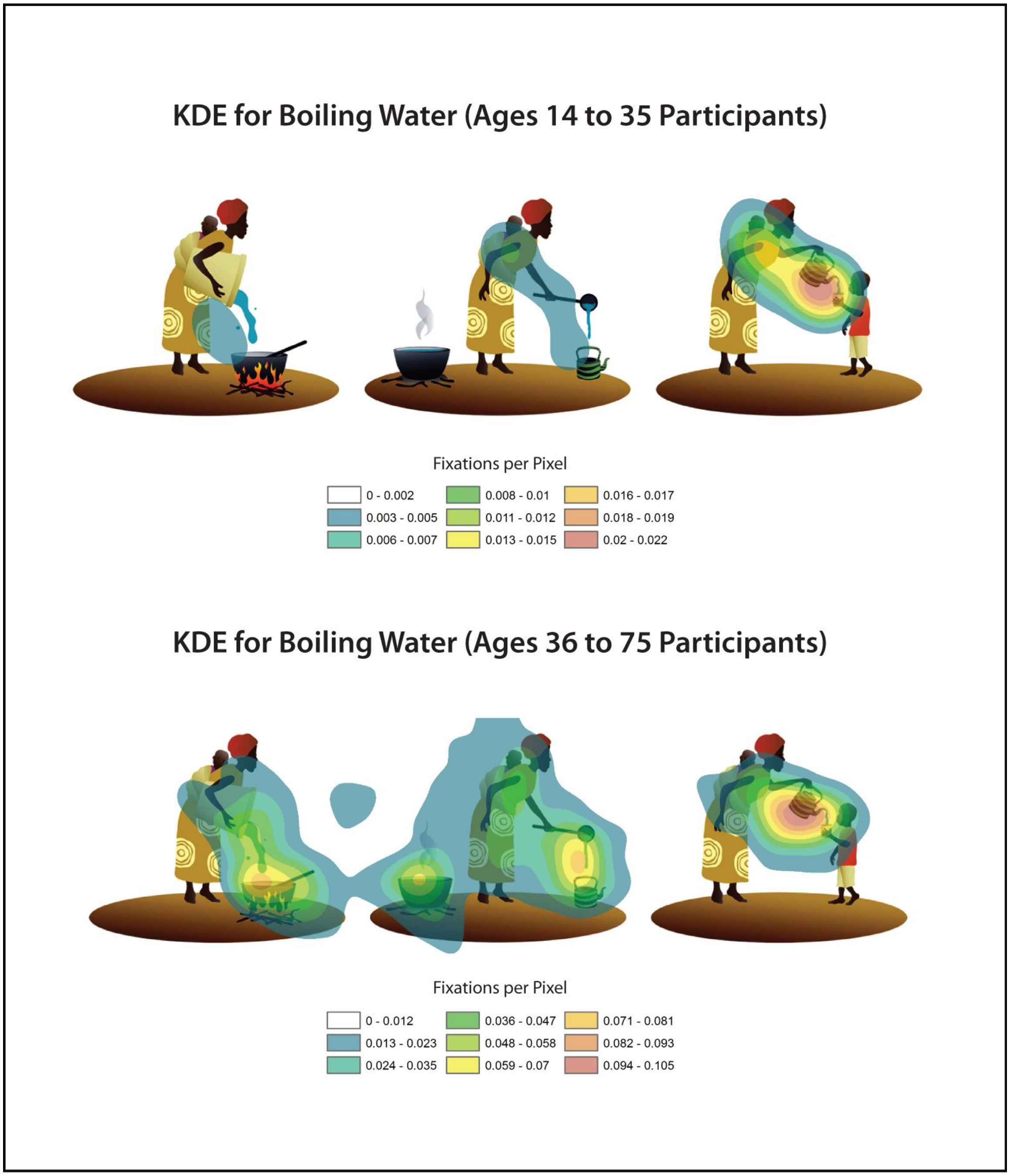

Figure A9. Kernel density estimation for Ages 14 to 35 versus Ages 36 to 75 participants (Boiling Water Visualization). Source: created by author from eye-tracking trials.

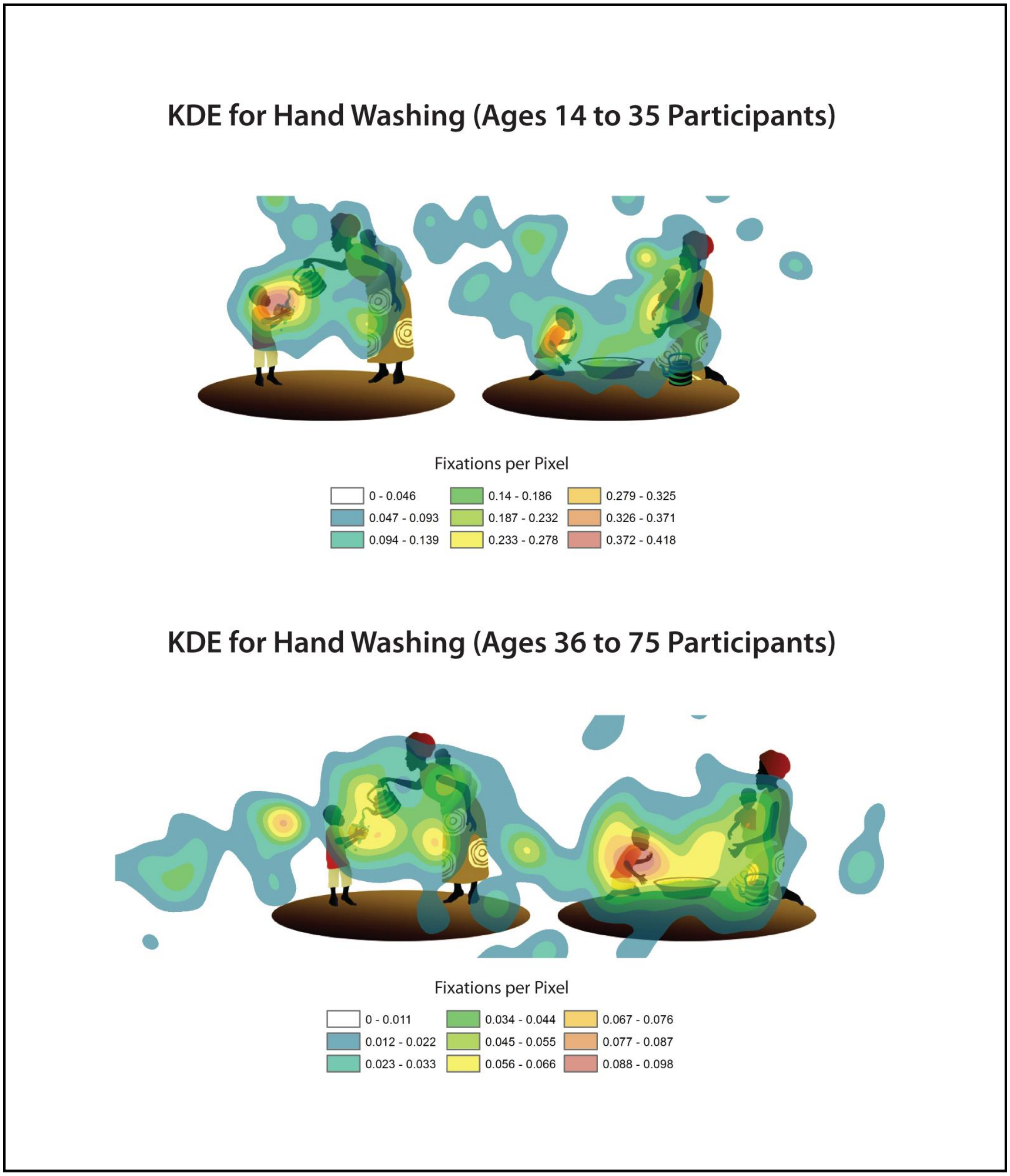

Figure A10. Kernel density estimation for Ages 14 to 35 versus Ages 36 to 75 participants (Hand Washing Visualization). Source: created by author from eye-tracking trials.

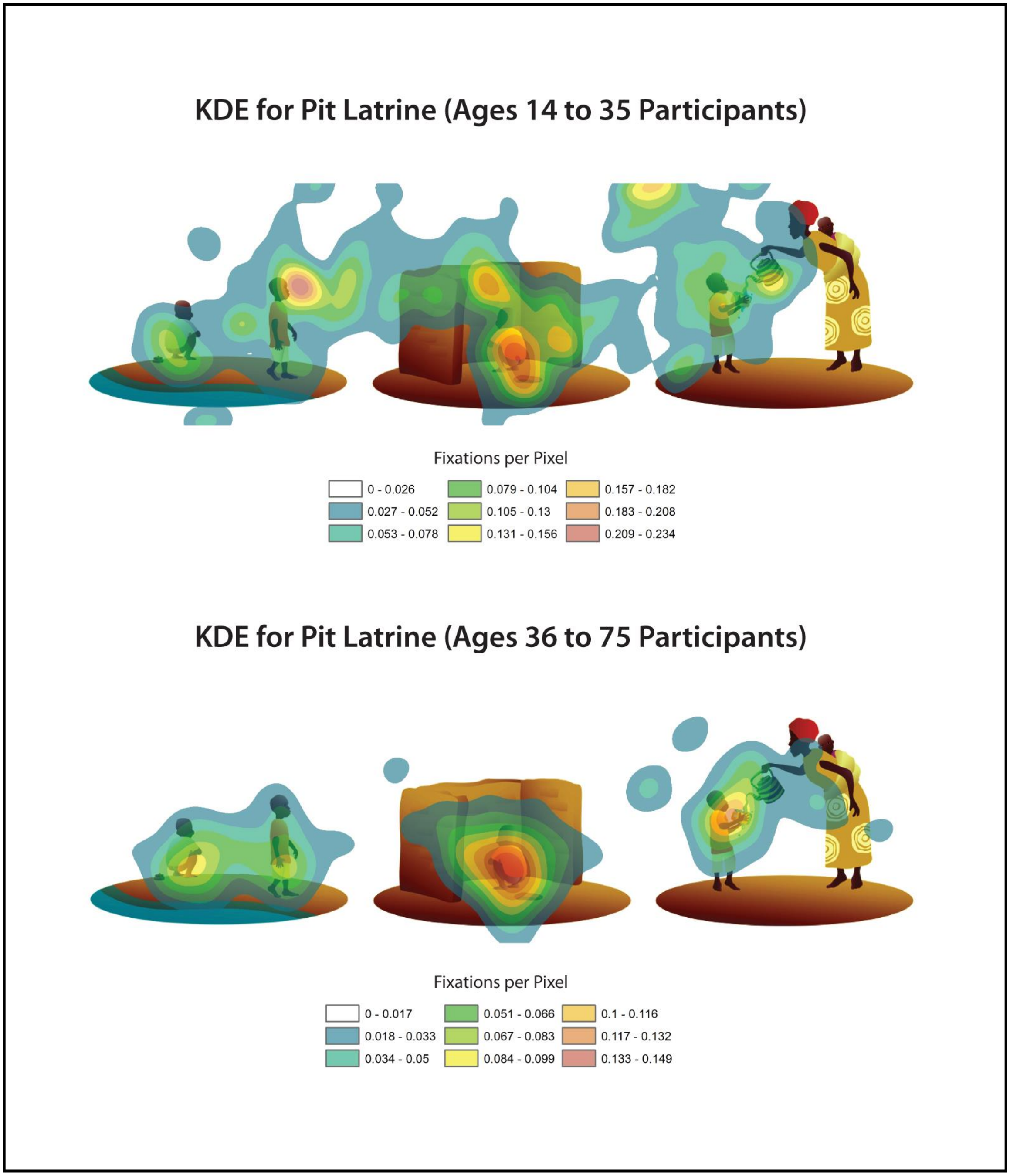

Figure A11. Kernel density estimation for Ages 14 to 35 versus Ages 36 to 75 participants (Pit Latrine Visualization). Source: created by author from eye-tracking trials.

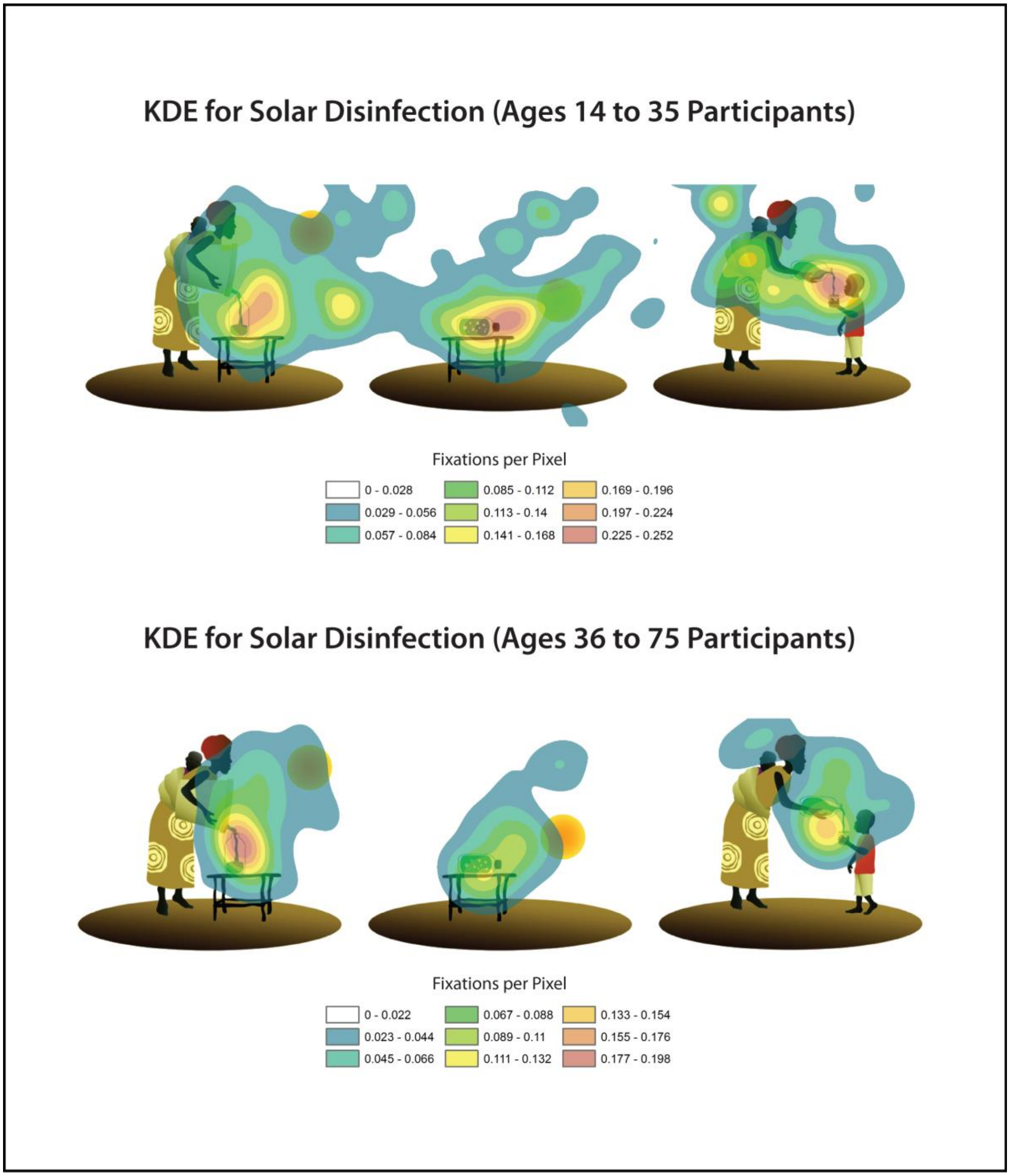

Figure A12. Kernel density estimation for Ages 14 to 35 versus Ages 36 to 75 participants (Solar Disinfection Visualization). Source: created by author from eye-tracking trials.

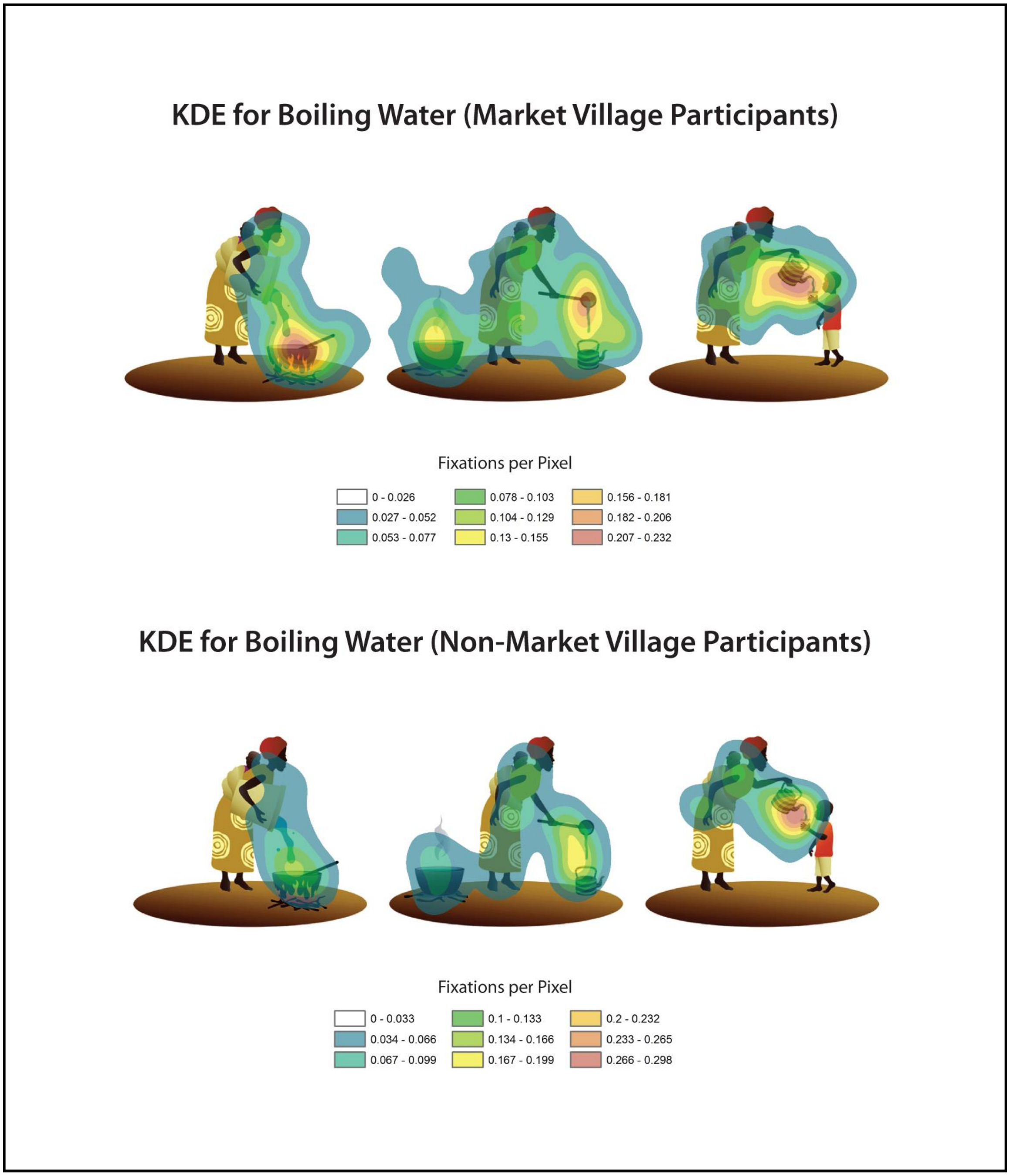

Figure A13. Kernel density estimation for market villages versus non-market villages (Boiling Water Visualization). Source: created by author from eye-tracking trials.

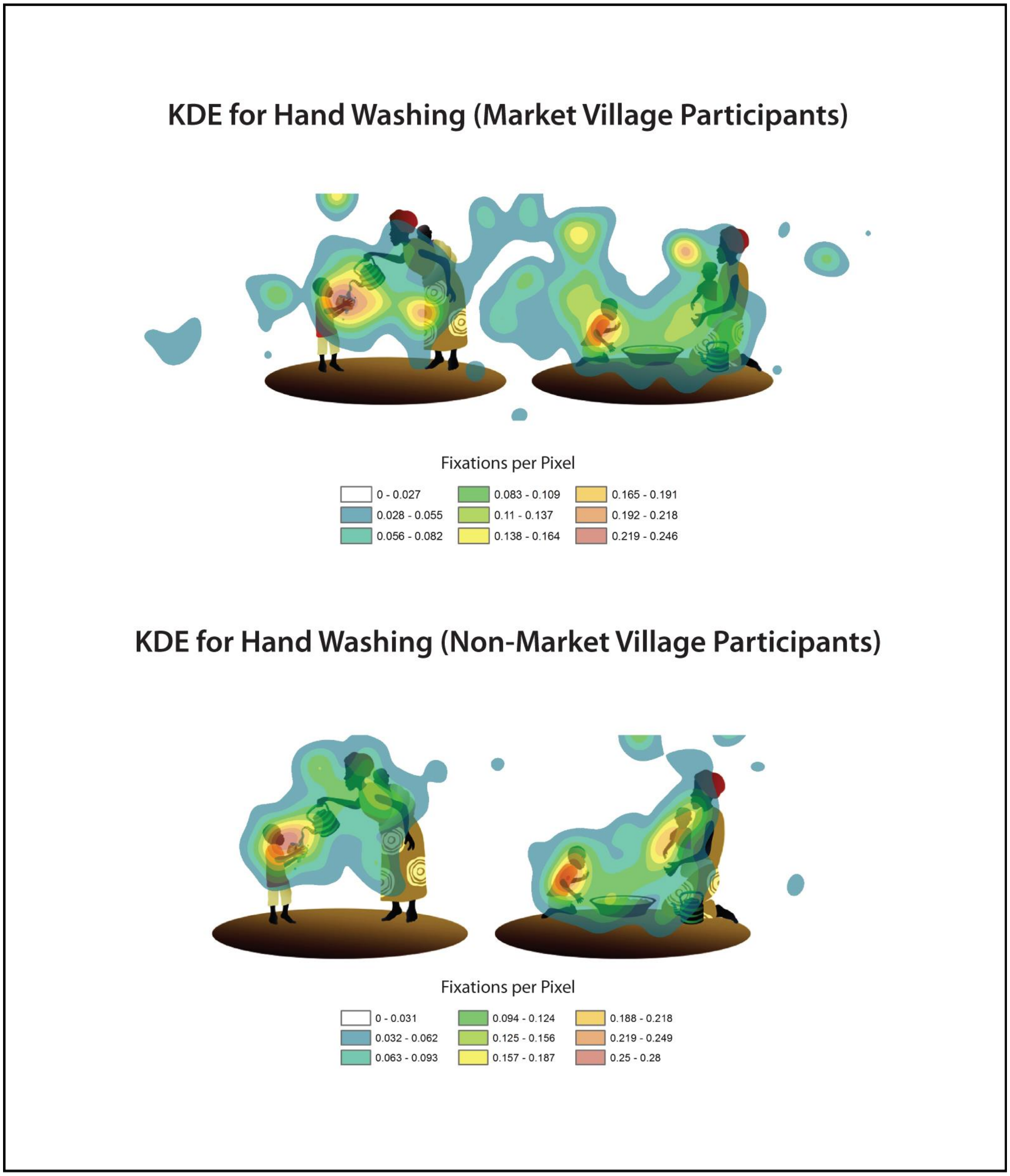

Figure A14. Kernel density estimation for market villages versus non-market villages (Hand Washing Visualization). Source: created by author from eye-tracking trials.

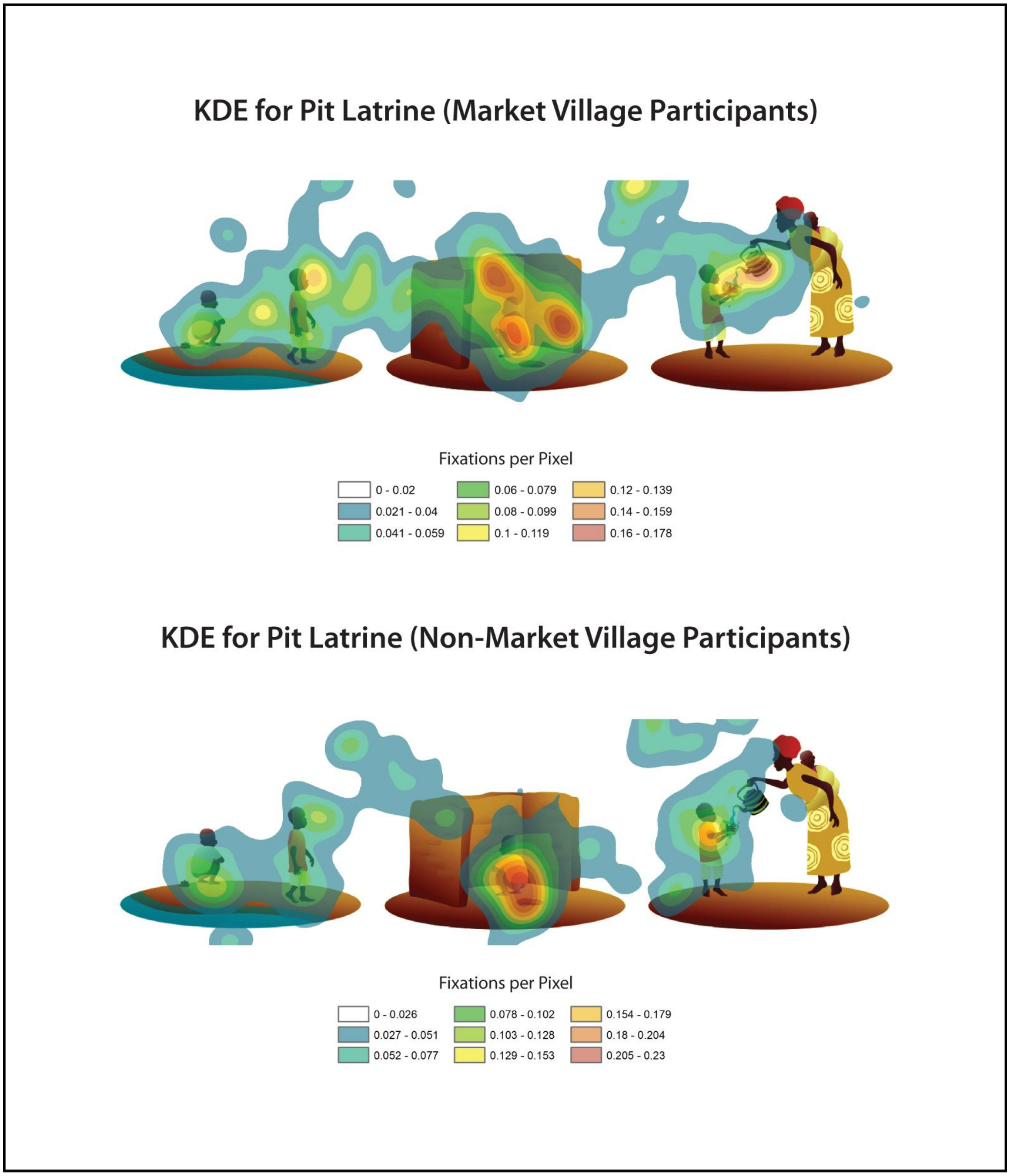

Figure A15. Kernel density estimation for market villages versus non-market villages (Pit Latrine Visualization). Source: created by author from eye-tracking trials.

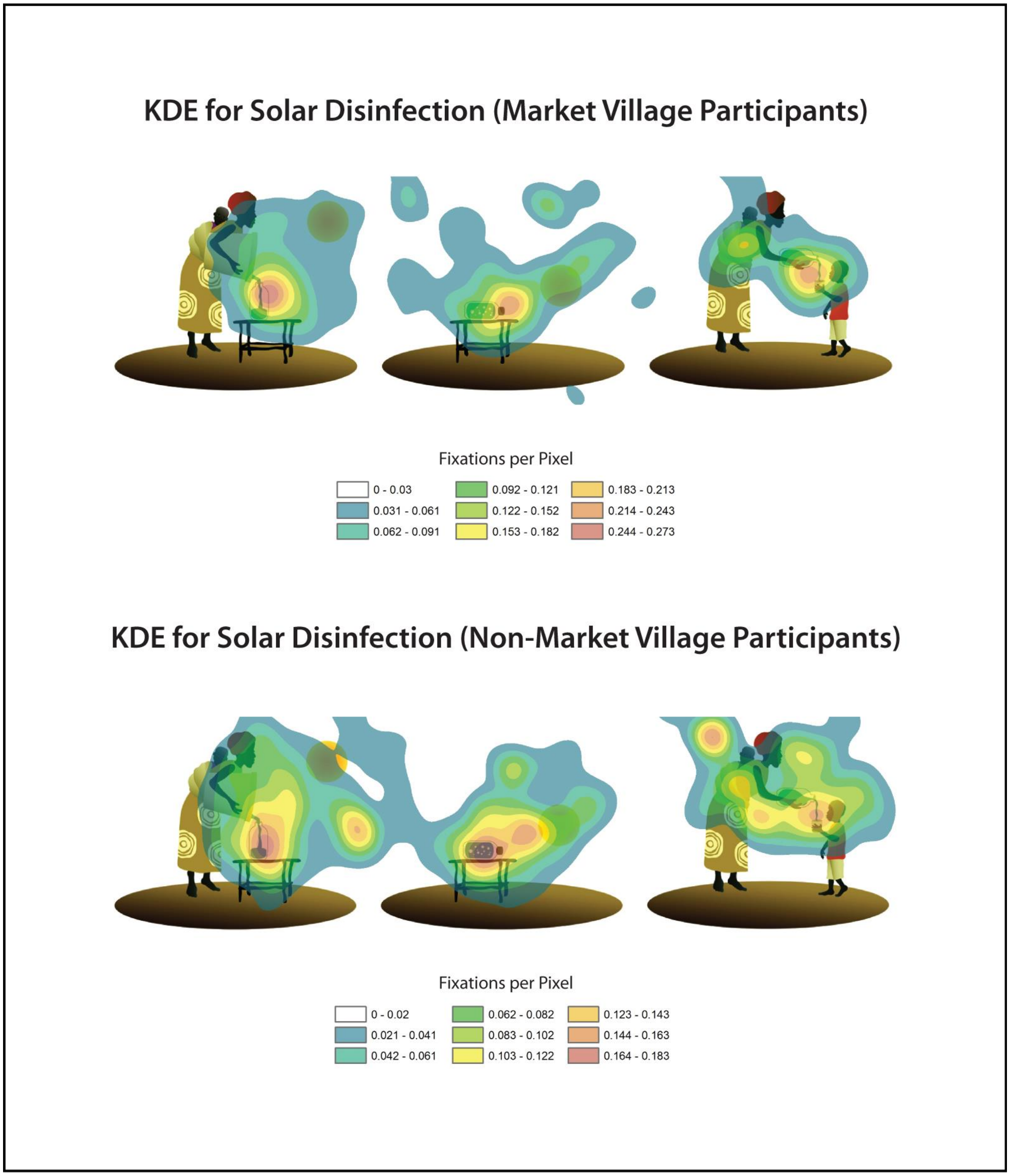

Figure A16. Kernel density estimation for market villages versus non-market villages (Solar Disinfection Visualization). Source: created by author from eye-tracking trials.

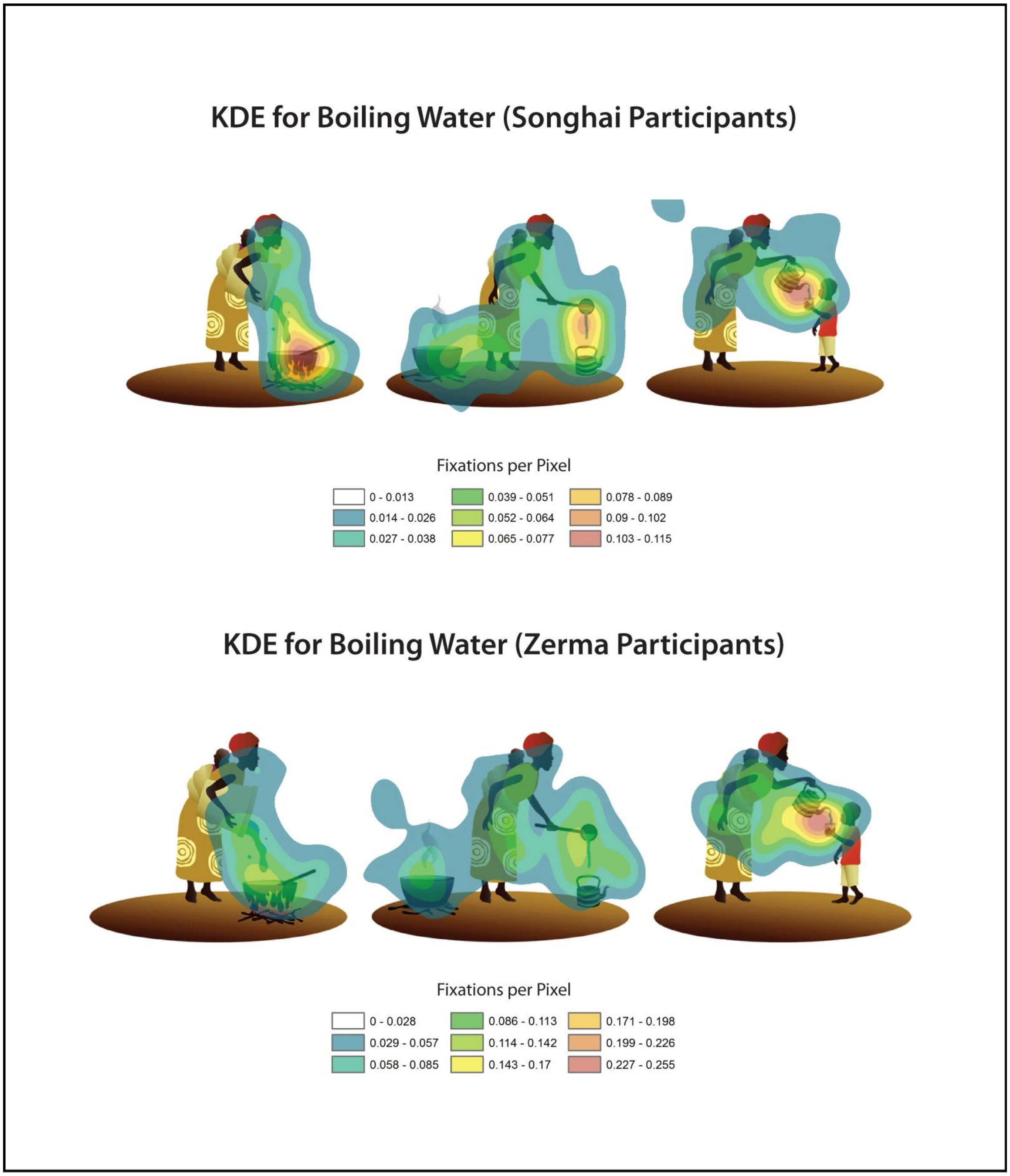

Figure A17. Kernel density estimation for Songhai versus Zerma cultural groups (Boiling Water Visualization). Source: created by author from eye-tracking trials.

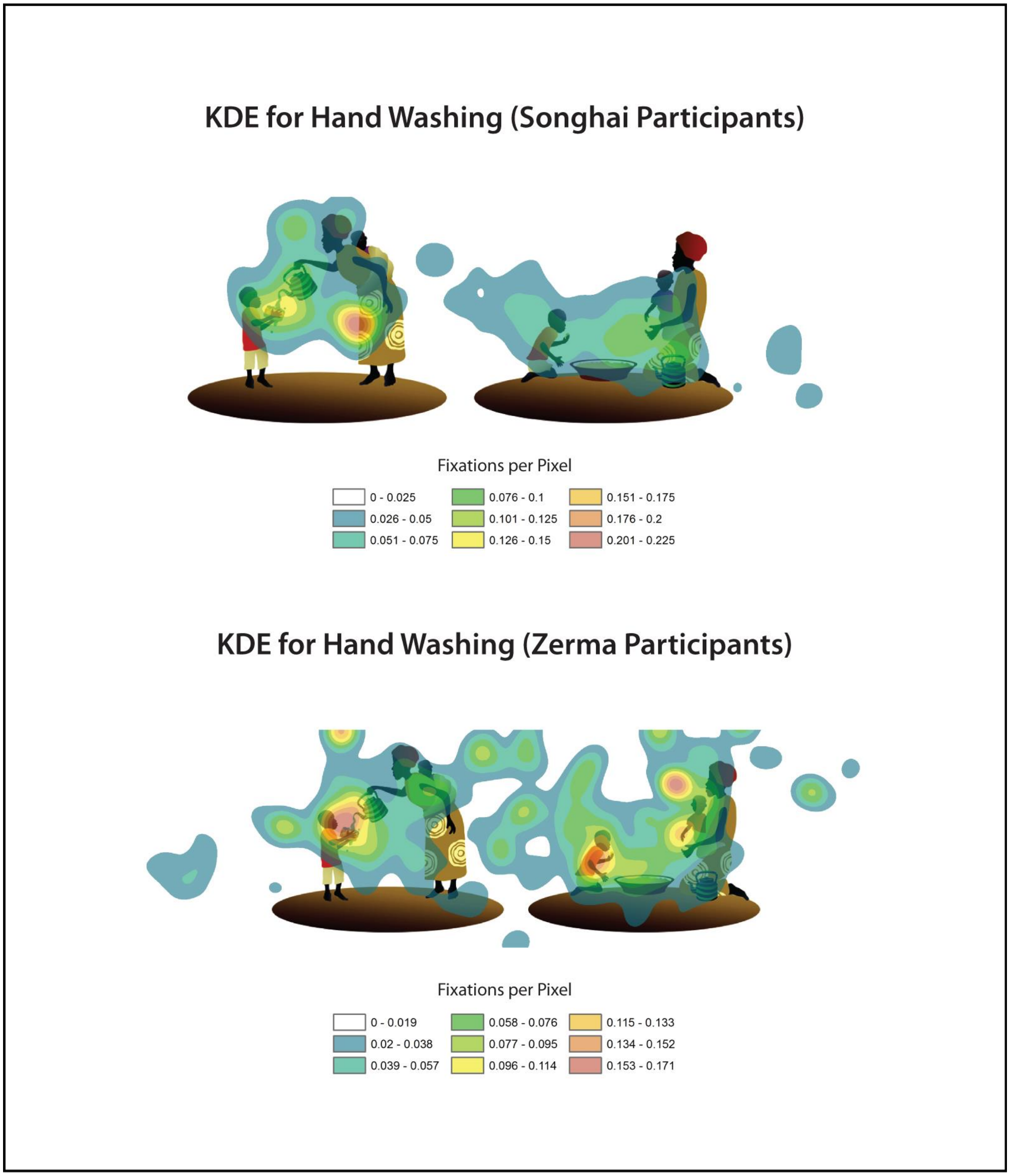

Figure A18. Kernel density estimation for Songhai versus Zerma cultural groups (Hand Washing Visualization). Source: created by author from eye-tracking trials.

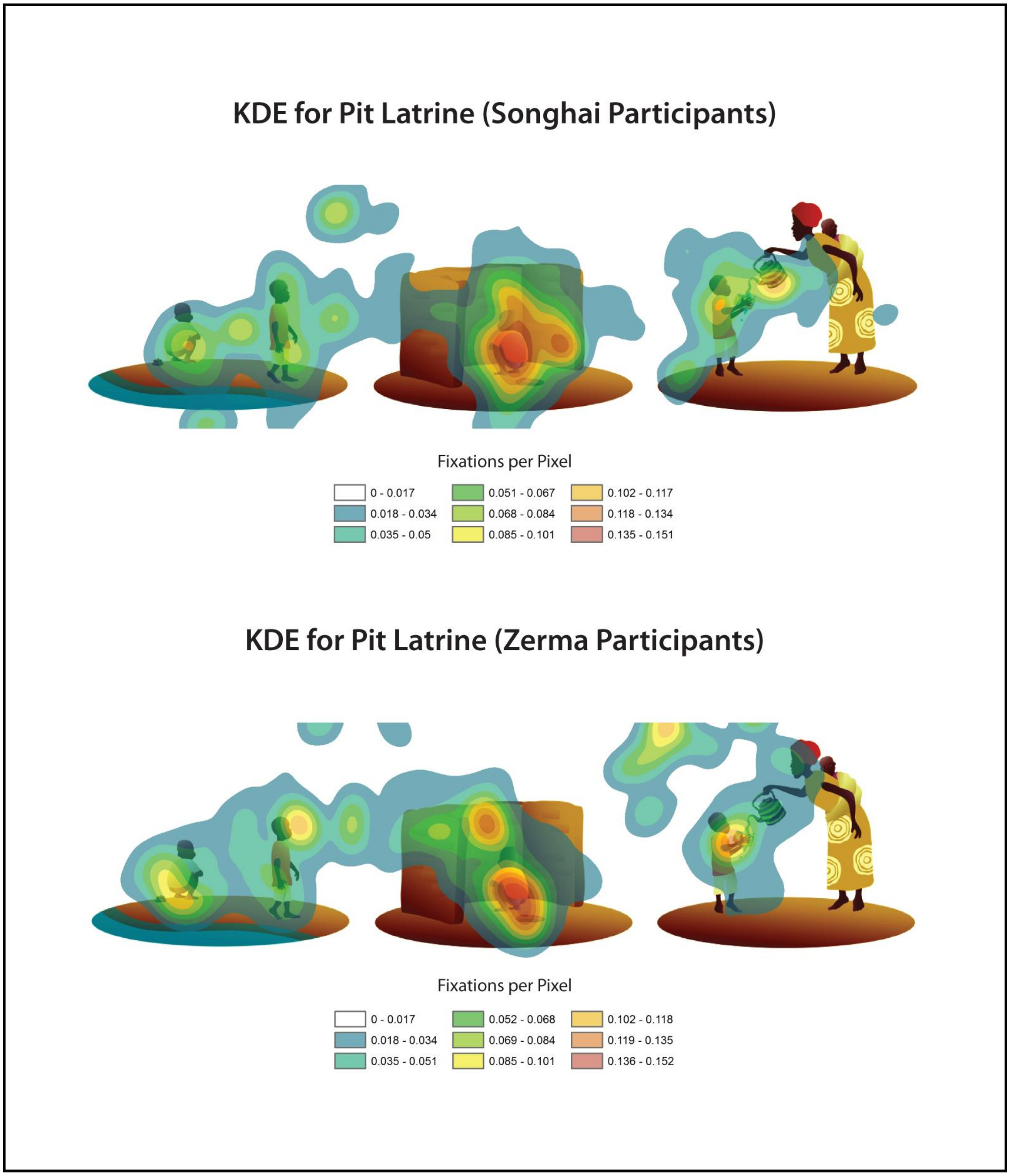

Figure A19. Kernel density estimation for Songhai versus Zerma cultural groups (Pit Latrine Visualization). Source: created by author from eye-tracking trials.

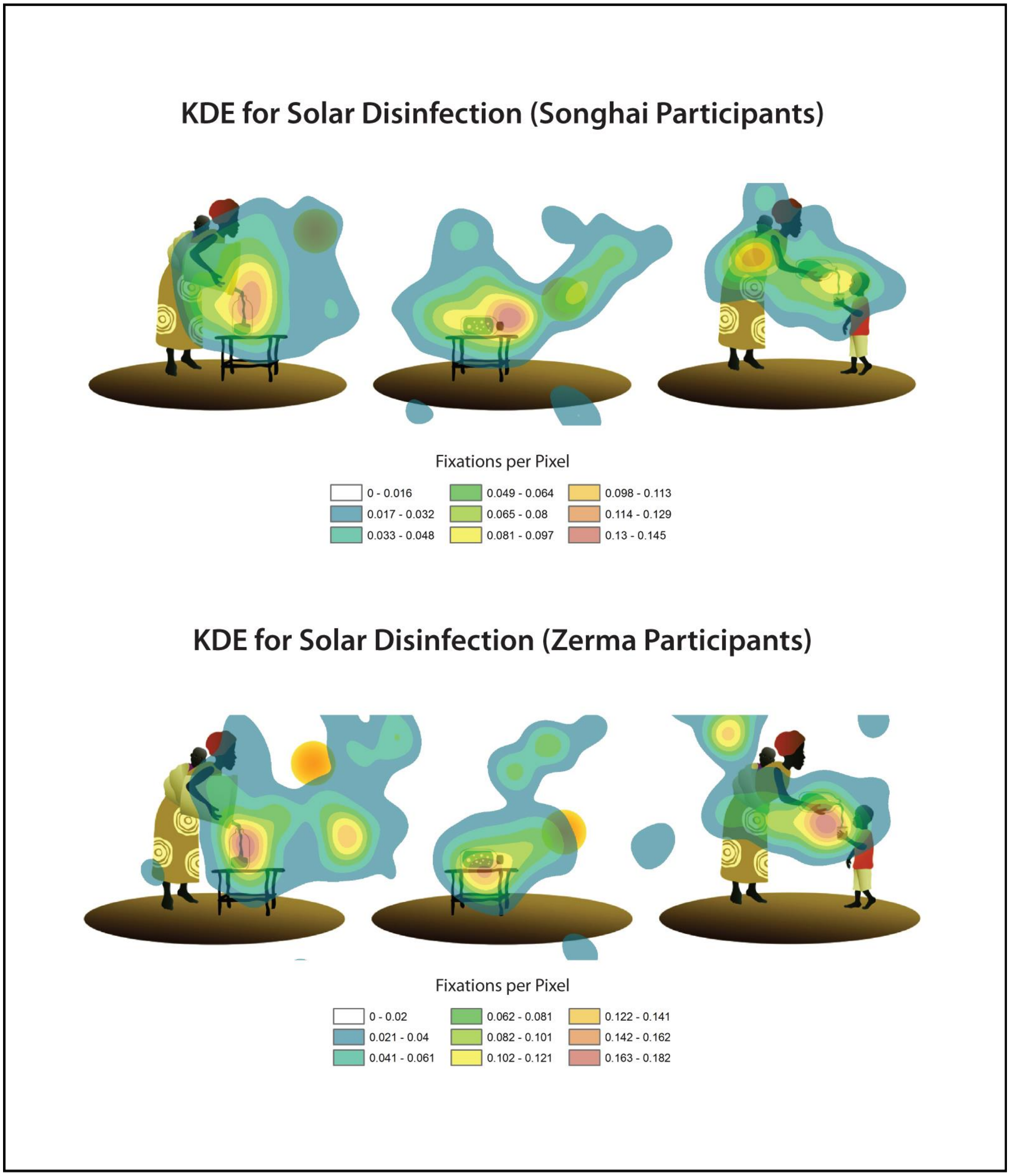

Figure A20. Kernel density estimation for Songhai versus Zerma cultural groups (Solar Disinfection Visualization). Source: created by author from eye-tracking trials.