Review Of Schistosomiasis Spatial Epidemiology In Zambia.

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Abstract - The development of spatial technologies such as Geographic Information Systems (GIS) and Remote Sensing (RS) has given insights in the understanding of diseases affected by environmental factors. However, knowledge on the applicability of such tools in the understanding of Schistosomiasis in Zambia is very limited. Partly, this is because the available research has not been systematically reviewed. The current study was a systematic review of empirical evidence on the application of GIS and RS in Schistosomiasis mapping, modelling and control in Zambia. Literature search was done on PubMed, Google Scholar and EBSCON host using the key words and Booleans "geographical information system" OR ''Remote sensing'' OR "mapping" OR "prediction" AND "Schistosomiasis" AND "Zambia. Nineteen (19) articles satisfied the inclusion and exclusion criteria and were therefore subjected to further scrutiny. Data extraction and presentation was in narrative form, combined with figures and tables. This review shows that the application of spatial technologies on Schistosomiasis in Zambia is still limited especially among local researchers.

Index Terms - Schistosomiasis, Geographic Information Systems (GIS), Remote Sensing (RS)

I. BACKGROUND

Schistosomiasis, commonly known as bilharzia in Zambia has been a major public health problem for a long time now. Currently, the estimated prevalence for schistosomiasis in Zambia stands at 26.6 % with an estimated 2.39 million people infected and another 3 million at risk of getting infection, though the World Health Organization estimates that those infected could be 4 million (1,2). The two types of schistosomiasis common in Zambia just like most Sub-Saharan African countries are; urinary schistosomiasis caused by *Schistosoma haematobium* and intestinal schistosomiasis caused by *Schistosoma mansoni.* However, the eggs of Bovine Schistosomiasis caused by *Schistoma mattheei,* have also been reported in humans in the country (3–5) . In terms of distribution urinary schistosomiasis *is* predominant and widely distributed compared to intestinal (2,6).

The life cycle of all the species is similar, complex and indirect with freshwater snails playing the role of intermediate host. Transmission for all the forms of schistosomiasis begins when human excreta in the form of urine or fecal matter containing schistosome eggs is released in fresh waters. Upon contact with water, the eggs hatch into the larval forms called miracidia which is infective to certain species of snails. The miracidia undergo asexual development in the snail intermediate host and transforms into another form infective to humans called the cercaria which release in water bodies. Humans that come into contact with infected water through domestic, recreation or occupation activities gets infected (7).

The schistosomes are maintained in snail intermediate hosts. The known intermediate hosts for schistosomiasis in Zambia are *Bulinus globusus* and *Bulinus africanus* for *Schistosoma haematobium and Biomphalaria pfeffeiri* for *Schistosoma mansoni* (8,9). Transmission of schistosomiasis in the country is focal and occurs in areas where humans and snails come into contact with water infested with cercaria. In the arears where the disease is endemic, changes to the environmental and climatic factors, water and sanitation control interventions, migration and distribution of snail intermediate hosts are key factors to consider when designing control programs (10). A deeper understanding of the environmental and climatic factors favouring the survival of the snail intermediate hosts is therefore a crucial factor towards designing control interventions for schistosomiasis (11).

Studies on ecological modeling have shown that the occurrence and transmission of diseases is an interaction of the parasite, agent and the environment. The transmission of most diseases is governed by the principles of population dynamics as other ecological systems. Reproductive rate and the carrying capacities of the local habitat are the governing concepts and they are influenced by broad environmental (vegetation, soil type, altitude) and climatic (rainfall and temperatures) conditions (12).

For schistosomiasis, the development of the parasite within the snail intermediate host is sensitive to Temperature(13) . Other than temperature, the presence of water also affects snail survival and the fact that different snail species inhabit different types of water bodies suggest that the influence of rainfall vary between species, with the greater effect on species exploiting temporary water bodies. Heavy rainfall may however wash away snail populations. Thus, it would appear that the effect of rainfall on the spatial variation of snail distributions might be modified by temporal variation in rainfall (14).Altitude affects both temperature and rainfall. In the snail intermediate hosts, altitude serves to restrict the distribution of snails by providing upper and lower limit of population and transmission dynamics. For freshwater snails, vegetation is key to their survival by being a source of dissolved oxygen while at the same time vegetation can be used as a source of food and a surface onto which the snails can lay eggs (15).

This evidence on impact of environmental and climatic factors suggests that emergence and spread of infectious diseases in a changing environment is complex and requires the development of robust methodologies and tools for risk assessment, early warning systems and policy making (16). Geographical information systems (GIS) and Remote Sensing (RS) are such tools.

GIS consists of a computerised system of hardware, software and procedures for management, manipulation, analysis, modeling, representation and display of georeferenced data and empirical survey infection data (17).Within a GIS system, data can be stored, retrieved and used professionally to model and map areas having spatial data sources . GIS works hand in hand with RS, a technology that enables scientists to study both the biotic and abiotic components of the earth surface. Using sensors usually onboard satellites, RS essentially measures energy reflected or emitted in distinct and specific electromagnetic spectrum. Each of the energy reflected is designated with numbers such that each number usually represents a specific characteristic on the earth's surface. Therefore, RS is an important tool in monitoring and observing the earth's landscape (18). Landscape structure, vegetation covers and water bodies. GIS and remote sensed data offer flexible methods for creating risk models for environmentally sensitive diseases, by letting the parasite/vector define itself based on its biological limits of tolerance (13,19–21).

This paper was a systematic review whose main purpose is the application of GIS and RS in schistosomiasis mapping, modelling and control in Zambia. It will also highlight the main environmental and climatic data used in schistosomiasis spatial modelling in Zambia, their sources and scales. The opportunities and challenges in the use of GIS and RS technologies in Zambia were discussed and also proposals suggested for future research focus in Zambia.

II. METHODS

Search criteria

We carried out literature search on PubMed (http://www.ncbi.nlm.nih.gov/sites/entrez), Google Scholar (https://scholar.google.com/) as well as EBSCON host using the same combination of terms and Boolean operators used by Simoonga et al., (2009) except that in the search "Africa'' was replaced with "Zambia''. Therefore, the following combination of terms and Boolean operators were entered: "geographical information system" OR ''Remote sensing'' OR "mapping" OR "prediction" AND "schistosomiasis" AND "Zambia, with no restriction on years. Snowballing technique was also used to review bibliographies or reference lists of previous and similar studies (22).

III. RESULTS

We present the summary of studies focusing on schistosomiasis risk mapping and prediction in Zambia using GIS and RS.

The search criteria produced 236 hits of which 217 were not eligible based on the inclusion criteria. The relevant articles were further classified based on the year of publication.

The main findings of the review from article review are summarized in figure 1, figure 2 and table 1.

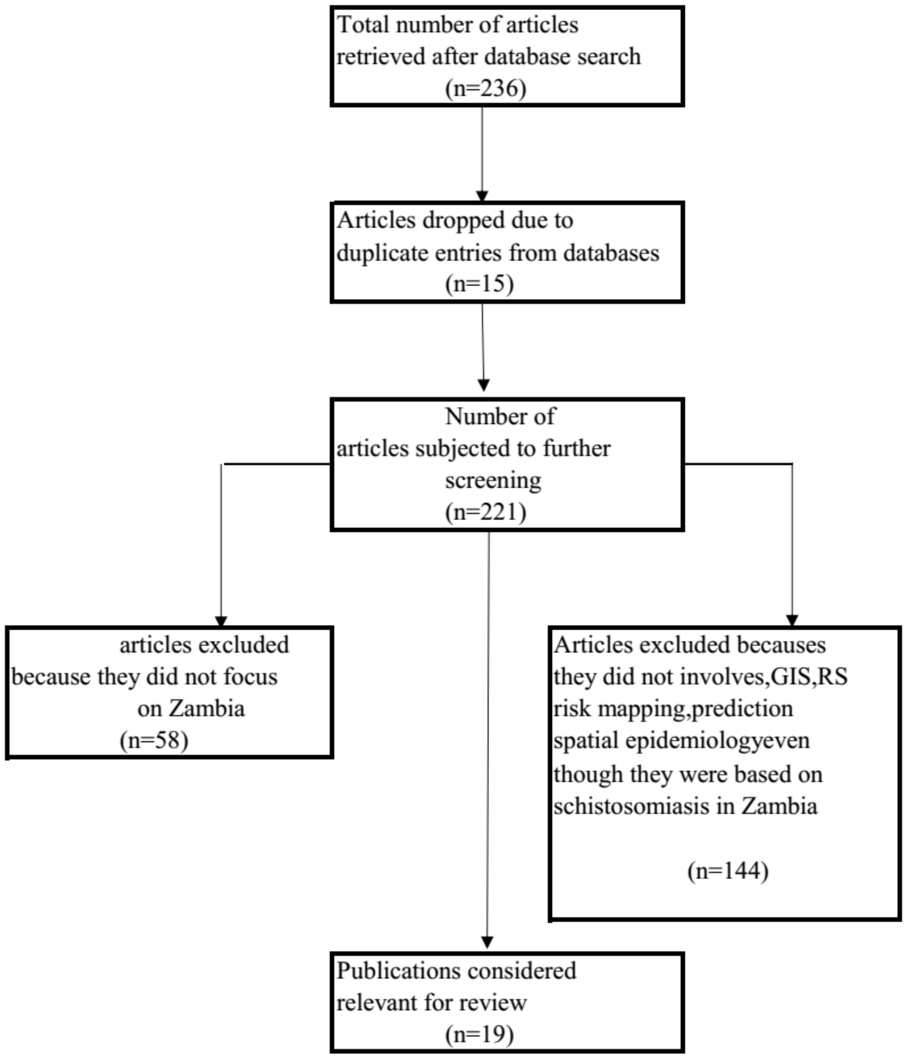

Figure 1: Criteria for selection of articles

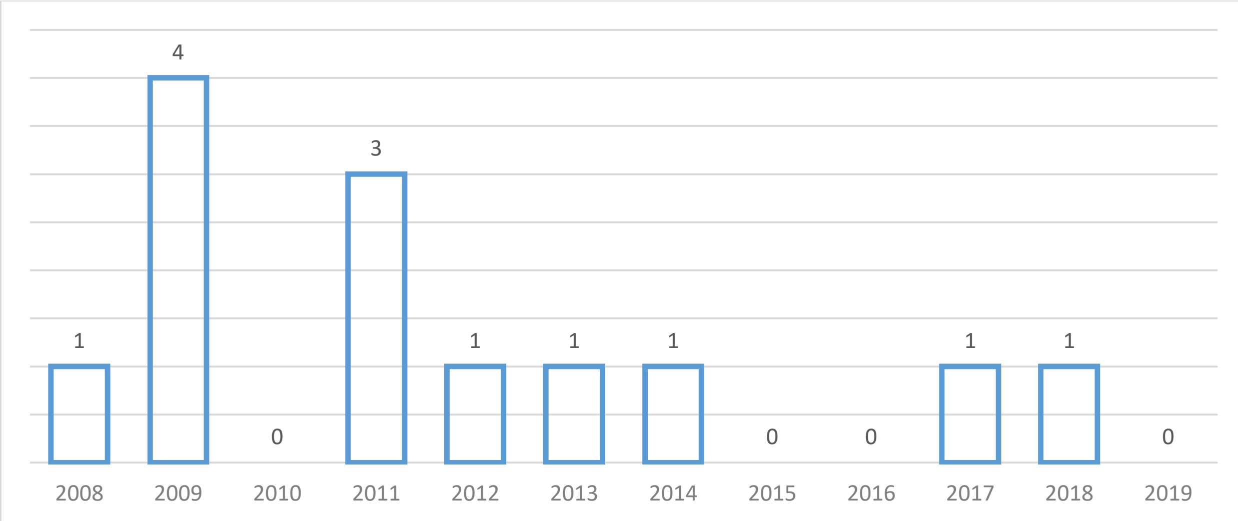

Figure 1:GIS and RS based publications by year in Zambia

The above figure shows that most publications on GIS and remote sensing in Zambia were between 2008 and 2011 where 8 publications (62%) were made compared to the 2012 to 2019 period which accounted for only 5 studies (38%).

Of the 13 studies that focused on the use of GIS and RS in Zambia, one study merely cited the use of GIS and RS technologies in Zambia. Another study was purely GIS based and only locations of the study sites and other polygon data were shown.

The remaining 11 studies used a combination of both GIS and RS technologies. Of the studies that used a combination of GIS and RS technologies, two studies were at micro - level, one at macro-level while the rest were at meso - level.

Methods for data management in these GIS and RS studies were similar based on the level for which such data was used. With all the studies that were at meso-level, Zambian data on schistosomiasis parasitology and malacology was pooled in a huge database, the GNTD database and then used at regional level. In one macro-level study, Zambian data was entered in a GNTD database and used at continental level.

Table 1: Summary of studies on GIS and RS in Zambia

Author and Year	Title of the study	Main Methods employed	Conclusion
(23)	The epidemiology and small-scale spatial heterogeneity of urinary schistosomiasis in Lusaka province, Zambia	Study locations georeferenced using hand-held global position system (GPS). Disease and snail data linked to GPS coordinates and altitude. RS data NDVI and Tmax analyzed using ERDAS Imagine 8.5 (ERDAS, Atlanta, GA, USA) software	Schistosomiasis risk infections was associated with altitude and NDVI. There was positive relationship between risk of infection and snail abundance. NDVI and snail abundance have influence on schistosomiasis transmission.
(23)	Remote sensing, geographical information system and spatial analysis for schistosomiasis epidemiology and ecology in Africa	GIS and RS based studies on schistosomiasis and snail intermediate hosts in Zambia and sub-Saharan countries reviewed between 19196 and 2008. RS data at micro, meso and macro scales for NDVI, Tmax, Tmin, LST, rainfall and water chemistry used.	A GIS and RS based research Node (CONTRAST) set up at University of Zambia, school of medicine to be a hub in sub-Saharan Africa to optimize control and transmission surveillance of schistosomiasis and other neglected tropical diseases.
(24)	The Schistosomiasis Control Initiative (SCI): rationale, development and implementation from 2002–2008	GIS used to link disease data collected by the Zambia bilharzia control program (ZBCP) and spatial information on climate, elevation and proximity to water-bodies. Bayesian geostatistical models used to predict prevalence of infection in the survey areas.	More efficient allocation of national control programme resources by focusing attention on high risk areas for schistosomiasis in Zambia.
(25)	Virtual globes and geospatial health: the potential of new tools in the management and control of vector-borne diseases	GIS and RS based database on biological, environmental and socioeconomic factors affecting schistosomiasis in Zambia and different parts of Africa created. Google Earth™ and Google Maps™ developed and used to communicate spatial data on schistosomiasis.	Information exchange on schistosomiasis under the hospice of CONTRAST project amongst 14 partner institutions from Europe (Belgium, Denmark, Switzerland and UK), and sub-Saharan Africa (Cameroon, Kenya, Niger, Senegal, Tanzania, Uganda, Zambia and Zanzibar) created.

(26)	Schistosomiasis and neglected tropical diseases: towards integrated and sustainable control and a word of caution	GIS used to delineate high-risk areas for chemotherapy-based control under SCI.	Number of school-going children to receive praziquantel estimated.
(27)	Large-scale determinants of intestinal schistosomiasis and intermediate host snail distribution across Africa: Does climate matter?	GIS and RS used to collect schistosomiasis disease and snail intermediate hosts data for Zambia and other African countries. Data digitized and georeferenced especially where historical data was used.	GIS and RS used to predict the potential distribution of schistosomiasis and snail intermediate host in the wake of climate change.
(28)	Modelling age-heterogeneous *Schistosoma haematobium* and *S. mansoni* survey data via alignment factors	GIS and RS used to collect schistosomiasis disease and snail intermediate hosts data for Zambia and other African countries. Data digitized and georeferenced especially where historical data was used. Zambian georeferenced data fed into GNTD database	Age-alignment factors to be included when estimating the prevalence of population-based risk of schistosomiasis, for large-scale modelling and prediction.
(29)	Toward an Open-Access Global Database for Mapping, Control, and Surveillance of Neglected Tropical Diseases	GIS and RS used to collect schistosomiasis disease and snail intermediate hosts data for Zambia and other African countries. Data digitized and georeferenced especially where historical data was used. Zambian georeferenced data fed into GNTD database	Zambian data on schistosomiasis and snail intermediate hosts is part of GNTD database and can be assessed by researchers anytime and used for disease risk modelling, targeting control interventions and disease monitoring and evaluation.
(30)	Determining Treatment Needs at Different Spatial Scales Using Geostatistical Model-Based Risk Estimates of Schistosomiasis	GIS and RS used to collect schistosomiasis disease and snail intermediate hosts data for Zambia and other African countries. Data digitized and georeferenced especially where historical data was used. Zambian georeferenced data fed into GNTD database	Schistosomiasis endemicity in Zambia is classified as moderate (10 – 50%) The estimated country-specific prevalence of schistosomiasis in school-aged children in Zambia put at 25.9%. With such prevalence, the estimated annual praziquantel treatment needs are between 1.1 and 1.2 million

Schur et al.,2013	Spatially explicit Schistosoma infection risk in eastern Africa using Bayesian geostatistical modelling	GIS and RS used to collect schistosomiasis disease and snail intermediate hosts data for Zambia and other African countries. Data digitized and georeferenced especially where historical data was used. Zambian georeferenced data fed into GNTD database	Zambia predicted as low risk for schistosomiasis. Prevalence estimated to be 26.6 % *S. haematobium* predicted as predominant species.
(31)	High Schistosoma mansoni Disease Burden in a Rural District of Western Zambia	GIS used for the mapping of study area. GIS analysis dine using ArcMap Version GIS 9.2 (ESRI) used.	The overall prevalence for *S. mansoni* in the area was 44%
(32)	Using the hierarchical ordinal regression model to analyze the intensity of urinary schistosomiasis infection in school children in Lusaka Province, Zambia	Study locations georeferenced using hand-held global position system (GPS). Disease and snail data linked to GPS coordinates and altitude. RS data NDVI and Tmax analyzed using ERDAS Imagine 8.5 (ERDAS, Atlanta, GA, USA) software	Schistosomiasis risk infections was associated with altitude and NDVI. There was positive relationship between risk of infection and snail abundance. NDVI and snail abundance have influence on schistosomiasis transmission.

IV DISCUSSION

The application of spatial technologies has provided insights in the understanding of the determinants and distribution of schistosomiasis in Africa. This is because the distribution of schistosomiasis is affected by climatic and environmental factors. The development of spatial tools has therefore enabled epidemiologists to develop models showing how the development and survival of the intermediate hosts is related to spatial parameters (17,20,33,34).

Despite spatial epidemiology through the use of GIS and RS offering a lot of promise in understanding the ecology and epidemiology of schistosomiasis across the world, thereby guiding control interventions, (17,19,34), the application of these technologies in Zambia is still limited. This is against evidence showing that the control of schistosomiasis in Zambia is still problematic even where interventions have been in place and with indications that climate change may affect the transmission of the disease (35,36).

This review shows that studies on spatial epidemiology are scanty as only two studies have been done at micro-level on the use of GIS and RS technologies in schistosomiasis in Zambia. This is similar to what is obtaining on the African continent where studies done by African researchers on schistosomiasis spatial epidemiology are generally few (37). The failure by most African countries to utilize spatial epidemiology technologies can be attributed to lack of capacity on the acquisition, processing and use of remote sensing data (38). Click or tap here to enter text. (32,39) GIS and RS technologies alongside Bayesian analysis have been used to examine small scale spatial heterogeneity of schistosomiasis in Kafue and Luangwa districts of Lusaka province. In these studies, schistosomiasis parasitology and malacology data were collected by geo referencing in all study locations using a hand-held GPS. Disease and snail data were analyzed alongside environmental and RS data in a GIS system. These studies concluded that environmental factors (altitude, temperature and NDVI) affected snail abundance and therefore influenced schistosomiasis transmission and distribution in the district. Varying intensity due to environmental factors can be used as a basis for control by control programs by targeting the resources to high risk areas. Therefore, GIS and RS technologies, can be used to produce maps showing hotspots for control purposes (40). Improvements upon these studies are required especially collecting GIS and high-resolution RS data at individual level and micro-scale (41).

The current review also shows that most of the studies on GIS and RS in Zambia were at meso-level and were conducted between 2009 and 2011.This period coincides with a European Union funded project, EU – CONTRAST Project, a multi-disciplinary alliance to optimize schistosomiasis control and transmission surveillance in sub-Saharan Africa (42). CONTRAST was a 4-year project (2006 – 2010) that brought researchers from 14 partner countries which included 4 European countries and 10 African countries, to better understand schistosomiasis epidemiology and transmission dynamics in sub-Saharan Africa (25,43). Zambia was represented in the project by the University of Zambia (UNZA) and was responsible for the creation, hosting, establishing and running of the GIS research node as well as collection of parasitological and malacological data on schistosomiasis in the Zambezi ecological zone. One of the major roles of the CONTRAST GIS node at UNZA was to create a database of georeferenced schistosomiasis data points from schistosomiasis prevalence surveys in Sub-Saharan Africa. The procedure for collecting this data has been described elsewhere (44,45).

Zambia's data on schistosomiasis (parasitology and malacology) was entered in the Global Database for Mapping, Control, and Surveillance of Neglected Tropical Diseases (GNTD). In 2011, GNTD database had 12,388 georeferenced data points for schistosomiasis from 35 African countries and 568 snail data from 20 African countries. GNTD is constantly being updated when new data is available. Therefore, meso-level studies in Africa where Zambia has been included have been made possible because of the GNTD database (Hürlimann et al., 2011; Schur et al., 2011, 2012; Stensgaard et al., 2013).

The schistosomiasis control initiative (SCI) used GIS and RS technology in Zambia between 2005 and 2007 during the Bill and Melinda Gates funded schistosomiasis control program. Bayesian geostatistical models were developed classifying areas in different risks to aid in the distribution of praziquantel for the treatment of bilharzia (Fenwick et al., 2009). The number of school-going children to receive praziquantel was estimated to be between 1.1 and 1.2 (27,29)million in Zambia while the country specific prevalence was estimated to be between 25.9% and 26.6 %. When the two parasites were compared, *S. haematobium* was more predominant than *S. mansoni* (26,27,30).

Building on the experience form the EU-funded GIS node of CONTRAST project, GIS and RS based database on biological, environmental and socioeconomic factors affecting schistosomiasis in Zambia and different parts of Africa were created. Google Earth™ and Google Maps™ were developed using the database. The platform allowed the different users in the project to add and share data, as well as moving around in the virtual environment through zooming and changing the position and viewing angle. Using this approach, the researchers were able to communicate spatial data on schistosomiasis (25).

The potential impact of climate change on the epidemiology and transmission of schistosomiasis and the implications of a changing climate on the snail intermediate host has been attempted using GIS and RS technologies (29). The review in its current form is not without limitations.

V CONCLUSION

GIS and RS technologies have potential to help us understand the epidemiology and transmission dynamics of schistosomiasis in Zambia and produce maps highlighting the hotspots where interventions are needed. The potential use of GIS and RS in the modelling, mapping and control of schistosomiasis in Zambia must therefore be emphasized. More studies on schistosomiasis and snail intermediate hosts at micro-level care required.

For the purposes of control, monitoring and evaluation, what is needed currently is to produce micro-level maps using historical data, while other maps post intervention can also be produced and the two maps compared during monitoring and evaluation.

There is also need to conduct studies on the potential impact of climate change on the distribution of schistosomiasis and snail intermediate hosts in Zambia. This is because of overwhelming evidence suggesting that climate change may affect the distribution of the disease and also that the environmental and climate factors which are remotely sensed may be affected by a changing climate (27) Modeling the distribution of schistosomiasis and soil transmitted helminthes using integrated approach must be encouraged. More snail data is needed which can be used to produce snail habitat suitability maps than the current practice where disease data is what is being used in model development (16). Future models on schistosomiasis must include socio-economic data at individual level at a much more refined scale.

The success of a predictive model is measured by how well it performs in real life situations. This review therefore recommends that confirmatory studies be done in the field to ascertain the performance of the models developed under spatial epidemiology (27,46).

To fully appreciate how the use of spatial technologies can benefit the country in schistosomiasis control, there is need to build capacity in the field of spatial epidemiology through trainings, research and spatial analysis tools (40). This will help alleviate some of the challenges which has made the country and Africa to lag behind in the field of spatial epidemiology. Capacity can also be built through collaborations amongst all parties involved in spatial epidemiology either directly or indirectly (47,48).

For Zambia, the experience from the CONTRAST project where the country was responsible for creating, hosting, establishing and running of the GIS research node will be a good starting point (23,25,29,42) The challenge with most African countries regarding research projects has been the failure to continue once donors pull out at project hand over and this could have been the same situation with Zambia regarding the GIS Node Project. African countries must therefore prepare for the transition and commit to full ownership of the projects including funding.

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