CHIA
Chronicles of Health Impact Assessment
Improving community health through health impact assessments

June 2018 VOLUME 3 ISSUE 1

HEALTH IMPACT ASSESSMENT OF THE CONSTRUCTION OF HYDROELECTRIC DAMS IN BRAZIL

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Abstract:

Background: Brazil´s dam-building plans in Amazonia imply substantial environmental and social impacts. This study evaluates the relationship between social, environmental, economic aspects, and impacts on the health status of the population of Rondônia, Brazil, due to the implementation of the Jirau and Santo Antônio hydroelectric dams.

Methods: A qualitative and retrospective Health Impact Assessment (HIA) is used to focus the study objectives. The information is arranged in a structured diagram that enables an outside reviewer to assess the aspects/ impacts relationship derived from the construction of the dams. This comes with outline recommendations for health risk management that can orient national health authorities. We selected a narrative review synthesis as the most appropriate approach for the study.

Results: The diagram network was built making it possible to analyze the impact changes caused by this enterprise in the health sector. Additionally, the model will serve in the implementation of a complete HIA approach in an attempt to quantitatively map the impacts and to propose recommendations.

Conclusion: The diagram pathway has been useful as an important tool for assessing a broader view of direct and indirect impact categories, serving as a basis for further evaluations and studies. This effort is very important for highlighting the priorities in the public policy decision-making process, serving as a basis for the Brazilian Health System.

Introduction

Brazil is undergoing a rapid demographic expansion and intensive development process, supported by the implementation of major infrastructure projects in the country to facilitate the development of the national territory (Brasil 2013; 2014).

To ensure the country's infrastructure and economic growth in the face of worldwide economic uncertainties, the Brazilian government created the Growth Acceleration Program (Programa de Aceleração do Crescimento - PAC) in its first phase in 2007, which has since promoted the planning and execution of major social, urban, logistical, and energy infrastructure in the country (Brasil, 2013).

Currently, the PAC is in its second phase, which started in 2010, in which investments are directed towards the energy sector with the construction of large dams, such as the Jirau (9° 15′ S 64° 38′ W) and Santo Antônio (08° 48′ S 63° 56′ W) dams, both located on the Rio Madeira in the municipality of Porto Velho in the state of Rondônia (Brasil 2013).

In the construction of hydropower plants, financial resources are mobilized from the public and private sectors through consortia; furthermore, many inputs, such as labor, machinery, equipment, and the construction materials needed for the work, are required. This mobilization often disfigures the region where the project will be installed, leading to impacts[1] with cross-border dimensions (Bortoleto, 2001; Brasil, 2013; Cruz and Silva, 2010; Fearnside, 2014; Rocha, 2014).

In large enterprises, the human and ecological impacts must be considered. According to World Health Organization, health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity (WHO, 1946).

To demonstrate the relationships arising from works of large enterprises and the health of the affected population, the need to compile evidence of health impacts and to represent them in an interconnected manner has been identified.

An understanding of the impacts of major projects requires socioeconomic and environmental studies, which should be presented according to the relevant legislation (CONAMA No 001/86) to minimize any possible negative impacts in the periods prior to the project, during the construction of the project, and after its completion. Thus, it is possible to perform a proper management of the impacts of the project (CONAMA, 1986; Cruz and Silva, 2010).

To minimize the negative impacts and maximize the positive impacts, any project in Brazil that will potentially cause an environmental impact must undergo the licensing process, according to CONAMA Resolution No. 01/86 and CONAMA Resolution No. 237/97. Resolution 01/86 defines the concept of an environmental impact assessment, its criteria, its guidelines, and establishes the mandatory Environmental Impact Assessment (EIA) and Environmental Impact Report (EIR) to exemplify the activities subject to the EIA/EIR. These reports have less formal language and represent key aspects of the EIA, and they are presented at public hearings to all stakeholders (Cunha, 2008).

However, the EIA/EIR does not adequately address the possible impacts on the health of the population and the health system (increased demand for medical care) based on the type of project because all constructions of large enterprises result in positive or negative impacts that directly reflect the population's wellbeing (Brasil, 2014).

Faced with this problem in the conceptual approach of the EIA/EIR, the World Health Organization (WHO) and the National Health Service of the United Kingdom (UK-NHS) consider that numerous activities of the public and private sectors produce health consequences (WHO, 2002).

Due to the fact that the health system can be overloaded by diseases provoked by environmental impacts, in an attempt to improve the health care approach in environmental impact studies, a new method of impact assessment for health has been proposed, the Health Impact Assessment (HIA). This methodology, which officially appeared in 1999 in a document called

[1] Environmental aspects are a result of activities, products, or services that can interact with the environment, causing or possibly causing environmental impacts, whether positive or negative. Environmental impacts are any change in the physical, chemical, and biological properties of the environment resulting from human activities(4).

the Gothenburg Consensus, is defined by the WHO as a set of tools and procedures to judge policies, plans, or programs by systematically evaluating the potential effects on public health (WHO, 1999).

The HIA is an established method in countries such as Canada, the USA, Australia, and the member states of the European Union. This tool allows one to evaluate a project and its potential health impacts and propose mitigation actions for health promotion (Brasil, 2014; Winkler et al., 2013). In Brazil, the concept was disseminated in 2014 by the Ministry of Health of Brazil with the publication of a national guide aimed at transferring the HIA methodology in the country. Its application has been encouraged in environmental licensing, aiming at large enterprises that could cause health impacts. The challenge faced by the Ministry of Health is the integration of the HIA and EIA/EIR (Brasil, 2014).

Considering this scenario, this study aims to identify and organize the direct and indirect health impacts and their determinants due to the environmental alteration caused by the construction of the hydroelectric dams on the Madeira River in the state of Rondônia, Brazil, considering national and international available data and references. We provide a review of various health effects associated with environmental, social, and economic aspects to provide a systematic, integrated, and clear overview of both the aspects and impacts with regard to the scope of the problem detailed in a network schematic diagram. Recommendations are proposed for the health authorities to pursue the constructors to seek means to protect the public health associated with the construction's impacts in the region and to obtain bases for health policy makers.

Methods

A qualitative and retrospective HIA was used to focus the study objectives. Rapid assessment was performed because of shortages of time and money as well as due to the difficulties of accessing data on projects and their construction. The HIA steps conducted in this study were Screening, Scoping and Appraisal (partial). The HIA relied on secondary data and expert informants and interviews to obtain essential qualitative data. The information was arranged in a structured diagram that enables an outside reviewer to assess the aspects/impacts relationship derived from the construction of the dams and to identify gaps that require further study and intervention. The product is a diagram network that enables one to easily visualize the relationships among the aspects and impacts associated with the environmental, social, and economic consequences of the dams' construction resulting in public health effects. This comes with outline recommendations for health risk management that can orient national health authorities towards indicating the steps required to formulate specific management plans through negotiation with local stakeholders.

We selected a narrative review synthesis as the most appropriate approach for the study because studies regarding health impacts derived from hydroelectric dams have been conducted in diverse types of traditional research, with widely different methodologies and often varied but nevertheless related research questions. This heterogeneity makes it difficult to apply a more traditional systematic review approach.

The main search engines used to source the literature were PubMed, Scientific Electronic Library Online, Latin American and Caribbean Health Sciences (Lilacs), and Google. The search was conducted using the terms "hydroelectric" or "power plants" and "Brazil" in combination with the terms "impact" or "effect", in English, Portuguese, or Spanish, without time limits. Moreover, the date of the last search was August 2016. The references of all of the retrieved original articles and reviews were assessed for additional relevant articles. International guidelines, government sites, grey literature, and expert opinions were also consulted for data and additional references. The articles' languages considered in this search were English, Portuguese, and Spanish.

The reading of the documents and articles was performed to refine the selection, leaving only those that addressed the issue related to the research objectives. The main articles and retrieved documents were reviewed with the focus on the diagram network impacts of the construction.

After collecting the information, a diagram network linking the environmental, social, and economic aspects and impacts was built using the CMAP software (developed by the Florida Institute for Human & Machine Cognition).

Study Area

The state of Rondônia (RO) is located in the northwest of Brazil and covers an area of 237,590.543 km2 with 52 municipalities, and it is bordered by the states of Amazonas to the north, Mato Grosso to the east, Acre to the west, and the Republic of Bolivia to the west and south (Figure 1) (IBGE, 2015).

Fig 1 Location of the state Rondônia in Brazil. Source: Prepared by the authors with the ArcGIS Online software

Both hydropower plants are located in the state of Rondônia on the Madeira River, in the municipality of Porto Velho. The first is the Santo Antônio hydroelectric dam, which has a reservoir with a flooded area of 421.5 km2 at its maximum level and an installed capacity of 3,568 MW, located at a distance of 8 to 10 km from the urban area of the municipality of Porto Velho (IBGE 2015; SANTO ANTONIO ENERGIA, 2016).

The second hydroelectric dam is the Jirau dam, which has a reservoir with a flooded area at its maximum level of 361.6 km2 and an installed capacity of 3,750 MW. This plant is on the Madeira River 120 km from the urban area of Porto Velho. The work of the Santo Antônio plant began in the second half of 2008, whereas the construction of the Jirau plant began in mid-2009. Both began partial power generation from 2012 (IBGE, 2015; ESB, 2016).

Results

Baseline Assessment

The state of Rondônia, whose capital is Porto Velho, is located in the north of Brazil, bordering Bolivia. This state represents 2.8% of the country, with an area of 237,765 km2, and contains approximately 0.8% of the Brazilian population, with 1,562,409 inhabitants in 2010 (Hacon and others 2014). Porto Velho is a municipality that has an area of 34,090 km2 and a population of 428,527 inhabitants (Cruz 2010).

The state of Rondônia has a predominantly young population and has also recently seen an increase in its population over the past 60 years. Between years 2000 to 2010, Rondônia saw an increase in the number of people who self-identified as colored or black, brown, and Asian; maintained its indigenous population; and saw a decrease in the share of people who self-declared as white in 2010 compared to the data from 2000. In 2010, the black or brown population in Rondônia represented 62.5% of the total population, whereas in Brazil, this ratio was 50.7%. A relevant piece of information is a 717% increase in the number of Asian people in Rondônia between 2000 and 2010, increasing from 0.2% to 1.4% in the population distribution and suggesting an intense migratory movement of this portion of the population.

The per capita household income of Rondônia increased by slightly more than 31% from 2000 to 2010, going from 78.8% of the national income to 84.3%, supported by an approximately 50% drop in the unemployment rate (from 9.88% in 2000 to 5.31% in 2010). In both census years, the unemployment rate in the state of Rondônia has remained below the national rate in Brazil, whereas the literary rate has remained very close. The Rondônia vehicle fleet grew by 330%, from 0.6% of the Brazilian fleet by 0.8%.

Life expectancy at birth for both men and women and for the total population in Rondônia remained below the Brazilian average and showed a small increase in the period, rising from 69.1 years in 2000 to 72.1 years in 2010 (IBGE census C).

With regard to the existing health establishments in the state and in the capital of Porto Velho, there was an increase in the number of health facilities, particularly after 2010. However, the number of establishments has not grown in proportion to population growth, and greater attention is required when taking into consideration access to health services and the conditions of service and assistance.

The Madeira River, which passes through the state of Rondônia, belongs to the Madeira River basin, which is the most important basin in the state and extends far beyond its limits within the lands of Brazil and the Republic of Bolivia, occupying an area of 1,244,500 km2.

The hydroelectric dams of Santo Antônio and Jirau on the Madeira river, both in the municipality of Porto Velho, have a total installed capacity of 7,318 MW. The two projects cost an estimated R$ 18.4 billion. The Madeira River, due to its importance has tributaries in Bolivia, Peru, Acre and Rondônia. This river is the main tributary of the Amazon (downstream), both in volume of water and sediments (de Souza Moret and Guerra, 2009). Several irregularities were verified during the dams' construction, such as the change of dam axis of the Jirau unit without the preparation of specific studies required by the Environmental Legislation, no study was presented on the impacts in the communities downstream of the plant. Moreover, there was no mitigation measures regarding the restructuring of the fish spawning area, compromising local and traditional feeding based on fishing, due to decrease of fishing areas (FURNAS et al., 2005).

In addition, the EIA/EIR states that there would be no impact on indigenous lands (FURNAS et al., 2005), which is false, since the Kaxarari indigenous communities in the extreme region of Katawixi, on the upper Candeias River, on the Karipuninha River, in Alto Jaci and Jacareuba on the Mucuinnão river (who live less than 20km from the hydroelectric construction) were not reported in the EIA/EIR and consequently does not present any assessment data or monitoring of the effects affected by the construction (Moret and Guerra, 2009).

Besides that, during the construction only 1,500 workers would stay as permanent workers. Between the first and third year would be around 15,000 contracted workers and, at the peak of the work, there will be the hiring of up to 20 thousand workers for only 3 months (Moret and Guerra, 2009). Unemployment itself is detrimental to health and has an impact on health outcomes, for example, increasing mortality rates, causing physical and mental ill-health, and greater use of health services (Mathers and Schofield, 1998). This shows the importance of exposing and gathering the health determinants, sometimes even unanticipated during the construction of the plants, in order to make it possible to mitigate negative impacts on future infrastructure works.

Network of aspects and impacts

To begin a systemic analysis of the aspects and impacts caused by the Jirau and Santo Antonio hydroelectric dams in Rondônia, this paper notes some of the positive and negative impacts related to all phases of the design and construction, showing the relationship between an aspect and an impact through a macro-systemic view. Table 1 shows the main potential aspects and impacts observed during the construction of hydroelectric plants.

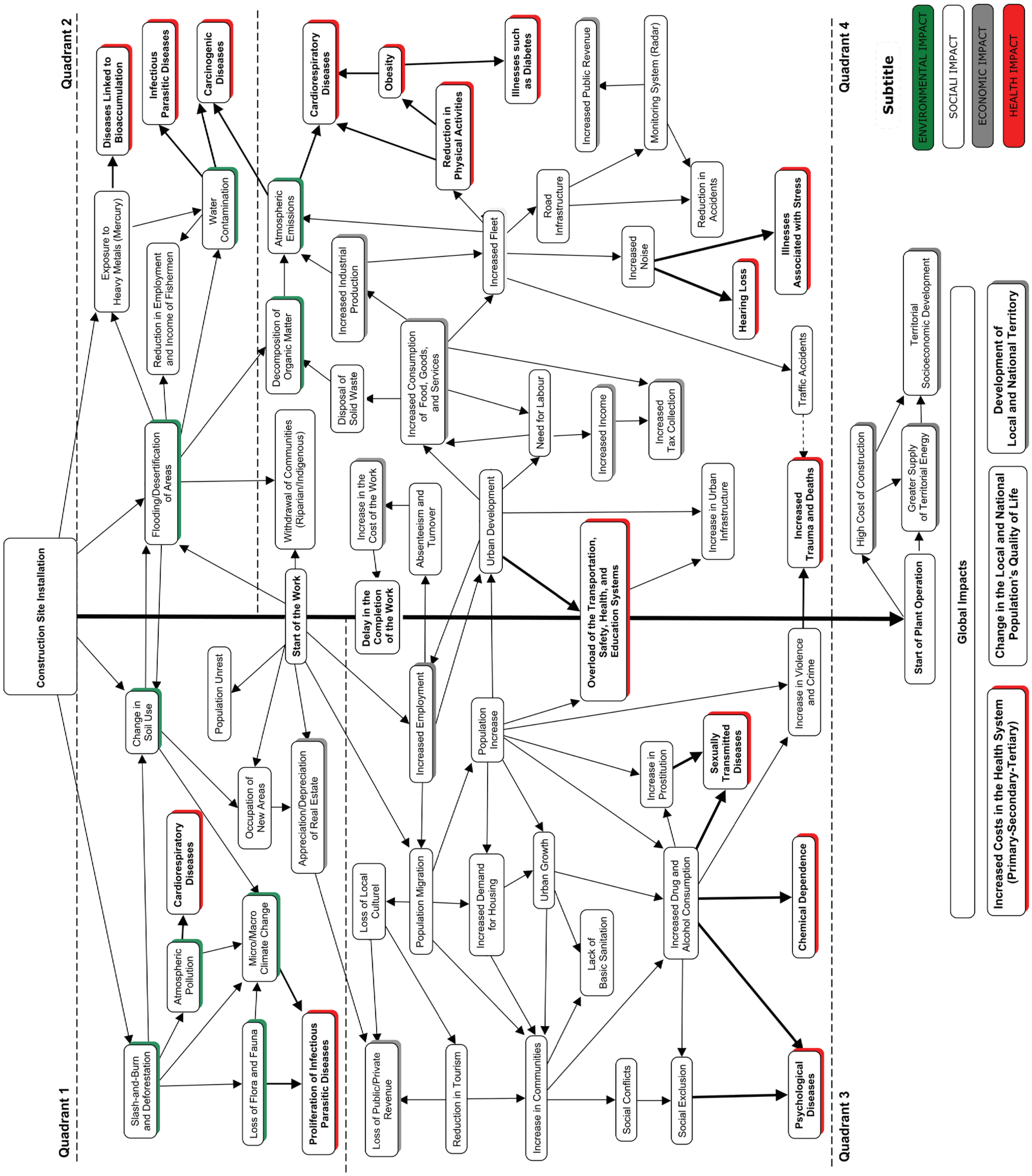
Table 1. Processes that induce impacts and actions and impacts/aspects resulting from the construction of hydroelectric dams in Brazil

Processes that induce impacts	Resulting actions	Impacts/aspects	Reference
Construction site installation	Occupation of land and changes in land use, deforestation, slash-and-burn, and floods	Elimination of flora and fauna; micro- and macro-climate change; proliferation of human infectious parasitic diseases.	Guerra and Carvalho 1995. Cunha 2008. Sanches and Fisch 2005. Alves and Justo 2011.
		Mobilizing communities (riparian, indigenous, and others) and changes in fishing activity	Guerra and Carvalho 1995. Alves and Justo 2011. Rocha 2014.
		Human exposure to mercury and heavy metals	Lacerda and Malm 2008. Almeida et al. 2005. Luca, 2012.
		Cross-border impacts	Marengo 2008.
Recruitment of labor	Rapid population growth and urban development	Unplanned territorial occupation, volatility of real estate values, loss of cultural heritage, restructuring of pre-existing economic activities, disorderly population growth, unemployment, slums, social marginalization.	Cruz and Silva 2010. Rocha 2014.
		Need for expansion of health, transportation, and education infrastructure	Cruz and Silva 2010. Franco and Feitosa 2013
		Increased vehicle fleet and air pollution, increased incidence of cardiorespiratory diseases on urban population, increased stress and greenhouse gases.	Queiroz and Motta-Veiga 2012. Fearnside, 2005a
		Increased noise and number of traffic accidents on urban population	Expert analysis

Increase of Population (local and migrant)	Increased income	Greater access to the consumption of alcohol, drugs, and prostitution, leading to violence and social exclusion	Queiroz and Motta-Veiga 2012.
		Increased tax collection	Expert analysis
		Population lifestyle change due to the purchase power increase	Queiroz and Motta-Veiga 2012.
		Change in eating habits, increase in unhealthy food outlets, increasing obesity	Queiroz and Motta-Veiga, 2012
	Increase in prostitution	Increase in sexually transmitted diseases	Expert analysis
	Increase in communities and social conflicts	Inequalities and social conflicts, increased drug use	Expert analysis
		Increase in neuropsychiatric disorders	Expert analysis
Delay in work completion	Elevated cost of the work	Worker turnover, fluctuation in workers' incomes	Expert analysis
Start of plant operation	Reduced supply of unskilled jobs and increase in skilled labor	Decrease in income and unemployment; increased social conflicts, Health impacts of unemployment	Expert analysis
	Increase in national electricity supply	Socioeconomic development, increased affordability of energy	Expert analysis
Global Impacts	Population increase	Increased costs in the health system	Expert analysis
	Change in the population's quality of life	Improved regional and national infrastructure	Expert analysis
		Territorial development	Expert analysis

In Figure 2, one can observe the link between environmental areas (highlighted in green), health areas (red), social areas (white), and economic areas (gray). This figure is divided into quadrants to facilitate viewing and understanding during the explanation.

Fig 2. Network of Aspects and Impacts.



The first stage in the construction of a hydroelectric dam is the installation of the construction site, which, in our study, started in the second half of 2008 and provided changes in the installed location. These changes can be observed in quadrants 1 and 2 in Figure 2. In quadrant 1, it appears that the occupation of the land can lead to a change in land use due to deforestation and slash-and-burn practices. This can cause the elimination of the diversity of flora and fauna. Due to slash-and-burn practices, an increase in the incidence of respiratory diseases may occur in the population caused by the emissions of the generated pollutants (Dominici et al., 2006).

By analyzing quadrant 2 in Figure 2, the flooding of areas for water storage purposes by the plant as well as other potential regional flooding due to the change in land use (observed in quadrant 1) and the installation of the construction site can be observed. This impact can cause the expropriation of areas by relocating the local riparian population, which is mainly composed of fishermen, indigenous people, and other population groups, to other locations. This way of displacement deprives people of their means of production and shifts them from their traditional ways of life.

Flooding in the riverbed can significantly change fishing activity and the life of the riparian community, which is often completely dependent on fishing for its subsistence. Other likely impacts are the proliferation of infectious parasitic diseases and community exposure to heavy metals. For example, mercury, released by erosion and ingested through water use and fish consumption, can trigger diseases linked to bioaccumulation, including neurotoxicity and loss of motor control and other health problems (Passos and Mergler, 2008).

In quadrant 3 of Figure 2, a probable population increase is observed due to the need for labor to start the project, which can generate an exacerbated migration of human resources to the construction site installation. The vast majority of this migrant population consists of direct and indirect workers (contractors) of projects that contribute to unplanned land occupation, with an urban growth beyond that tolerated by the city (Moret and Guerra, 2009)

Thus, there may be the expansion of poor communities with inadequate housing conditions due to the housing demand generated by migration. In many cases, these are areas that lack basic sanitation and with social conflicts, including indigenous lands, leading to the social exclusion of the population or the individuals who live in the community. Another fact is that this change in the place brings a loss of cultural identity, leading to a decrease in tourism in the region and, consequently, lost revenue. This scenario causes a change in the price of real estate or the appreciation of some areas over others (FURNAS et al., 2005).

Another change in the population's life is the increase in income provided by the supply of employment. This increase in income boosts the purchasing power of the local population, allowing access to goods and services that improve the quality of life. However, possible negative aspects consist of a higher consumption of alcohol and drugs, which also leads to increased prostitution and violence, producing direct effects on the population's health and wellbeing, such as psychological diseases, sexually transmitted diseases, fractures, and trauma caused by violence.

Traumas are also accentuated due to traffic accidents, as noted in quadrant 4. The increase in population attracted to the region affects the morbidity and mortality rates of non-communicable diseases, especially those of external causes, such as accidents and violence (Silveira, 2016). This effect can have several reasons, among them comes from the change in behavior in the population because the increased income begins to consume a greater number of goods and services, notably the acquisition of cars and motorcycles, in addition to the expansion of industrial production to meet the need for transportation.

This increased demand can cause environmental consequences, such as a greater generation of solid waste and atmospheric emissions. Atmospheric emissions are the result of the increased vehicle fleet and the increase in industrial production because the burning of fossil fuels releases gases into the atmosphere that are harmful to health. Consequently, there may be an increase in the incidence of respiratory diseases in the population, such as pneumonia, bronchitis, emphysema, asthma, cardiovascular ischaemic diseases, and cancer, which are diseases commonly associated with air pollution (Kampa and Castanas, 2008; Abe and Miraglia, 2016). In addition to these diseases, it is also possible to trigger stress and obesity due to decreased physical activity, and pollution exposure (Madrigano et al., 2010).

Additionally, in Quadrant 4 in Figure 2, one can observe the need for infrastructure in the state of Rondônia, such as roads, avenues, streets, bus terminals, basic sanitation, and others to bring an improvement in people's quality of life.

Another impact in the increase in the fleet, according to expert analysis, is the generation of noise for residents who live in the vicinity of roads, increasing the morbidity associated with stress.

A transversal fact that typically occurs is the delay in the completion of the work (quadrants 3 and 4 in Figure 2), which occurs due to factors such as the lack of raw materials, strikes and absenteeism by employees, financial resources, and environmental conditions. All of these factors increase the cost of the work and may lead to dismissal.

By analyzing quadrant 5 of the network of aspects and impacts, one can verify the global results of the operation of the hydroelectric plant, which can be positive or negative. The positive results are the increase in quality of life in the country due to higher energy availability and increased purchasing power. The negative results include an accelerated migration, increased health demand in both the public and private network, and increased demand for education, which served a certain number of people prior to the project installation and must meet an increased demand from people but with the same infrastructure after the installation.

Discussion

The socio-environmental impacts from the installation of hydroelectric power plants have received increasing attention from researchers and the media in both the national and international conjunctures. The problems arising from the implementation of these works, both social and environmental, are broader than imagined. In this sense, this is the first time, through an extensive bibliographical survey, that the direct and indirect health impacts of the population, derived from hydroelectric projects, have been gathered in Brazil. These effects were addressed in a systemic and networked way, showing the interconnections between environmental effects and people's health.

The diagram network impacts elaboration is an efficient and structured method to begin an HIA and facilitates the reading of the various impacts and their correlations, allowing the implementation of mitigation actions (policies and actions) at the source, preventing a collapse in the health system. In this case, the effects were analyzed retrospectively, and the experience gained from these analyses will serve as a substrate for future projects on the same topic (Harris, 2007; Harris et al. 2007).

To build the diagram network impacts (Figure 2), from the starting point, there were premises that facilitated the understanding of the correlation of the wide range of existing variables, their causes, and the ultimate effects on public health (Bortoleto, 2001; Guerra and Carvalho, 1995; Queiroz and Motta-Veiga, 2012).

The objective of this study was to demonstrate the possible consequences of the hydropower project by creating a matrix of interconnected aspects and impacts, called the network of aspects and impacts. The target study population was the riparian, urban and indigenous population. Nothing in the literature, in which there is a broad view and the dynamics of changes caused by the implementation of a project of this size, similar to this network, has been found. This view is pioneering and allows both a global and a specific analysis of existing problems or potential damage due to the changes stemming from an intervention.

The importance of creating a holistic view is noted by Wehnham (2011), who describes the importance of a multi-sectorial vision, including sectors such as transportation, energy, and the environment, aiming to understand the health consequences (Wernham 2011).

The network of aspects and impacts presents a multi-sectorial vision. This is noted from the installation of the construction site, which causes initial impacts such as the occupation of land and changes in land use through deforestation and slash-and-burn, thereby eliminating the flora and fauna (Lerer and Scudder, 1999). Studies in Australia, which has more than 446 hydroelectric dams, show that dams and weirs affect the fluvial fauna and flora (Teodoro, 1995, Kingsford, 2000, Thoms and Walker, 1993) and that the ecological impacts on lowland flooded areas are still poorly understood because habitat loss may have widespread impacts on native fish and waterfowl. Associated with road construction and the urbanization of the area, one can observe that there is the loss of native habitats, causing deleterious effects on the population of bees, birds, animals, and riparian populations as well as a significant change in eating habits, with most food being purchased in nearby cities rather than produced locally or collected (Schmidt 2011). It results in the loss of access to traditional means of life, including agriculture, fishing, livestock, and plant extraction (Cruz and Silva, 2010).

This leads to micro- and macro-climate change, which, combined with previous environmental changes, exacerbates the proliferation of infectious parasitic diseases for humans (Alves and Souza 2011; Cunha 2008; Guerra and Carvalho 1995; Sanches and Fisch 2005). In addition, silting and sedimentation in the soil due to the construction of the dams have affected the water quality of the region of the enterprise, increasing the eutrophication phenomenon, damaging the fauna and the aquatic flora of the reservoir and, with this, the quality of the water of this region, which may constitute not only an environmental and economic problem but also a public health one (Carneiro and Rubin, 2007).

The increase in vector-borne diseases due to the construction of hydroelectric dams is a recurring problem and was also reported during the construction of the dam in Turkwel Gorge, a semi-arid region in Kenya, which was completed in 1994 (Renshaw et al. 1998). Since then, concerns about the environmental and health impacts have been reported, and authors have noted the proliferation of the main vector of malaria, Plasmodium falciparum, near the reservoir of the hydroelectric plant (Pantoja and de Andrade, 2012). Schistosomiasis was also an endemic disease in Kenya, but authors suggest that there may be a high risk of an increase in cases of schistosomiasis due to the population migration to the construction site. This risk has also been identified for leishmaniasis. Nomadic herdsmen, fishermen, and farmers have been identified as high-risk groups for these diseases (Renshaw et al, 1998). In our study, the threat of the proliferation of vector-borne diseases during the construction of large hydroelectric projects in tropical regions is also a reality and impacts the local riparian population, including the indigenous population of Rondônia. During the construction of the Rosal Dam, in south eastern Brazil, authors have revealed the potential in the area for the transmission of malaria, schistosomiasis, and cutaneous leishmaniasis (Rezende et al, 2009). Among the infectious parasitic diseases, the researchers involved in data collection in the hydroelectric dam in Kenya also identified a risk of an outbreak of the disease known as "Rift Valley Fever", a viral disease transmitted by mosquitoes, because the construction site of the hydroelectric dam has a combination of people, water, animals, and mosquitoes that facilitate a virus outbreak (Renshaw et al, 1998). In Brazil, there is also the risk of outbreaks of mosquito-borne diseases, specifically dengue, yellow fever, and malaria, which are endemic in the Amazon region, where hydroelectric plants on the Madeira River are installed (Britto, 2007).

The change in land use is also a by-product of floods that occur due to the plant, which has resulted in the mobilization of riparian communities, changing people's way of life (Guerra and Carvalho, 1995; Rocha, 2014). The population flows that are configured from the construction of the hydroelectric plants usually occur through two processes in the Amazon: the search for territories of contingents looking for work that come to occupy this area and that of lands' desocuppation, marked by the expropriation of the population of the areas of influence of the reservoir. This results in a behavior of migratory flows and refluxes, with no sustainable convergence of public policies and investments (Cavalcante et al. 2011). In Canada, the construction of the La Grande Hydroelectric Complex, known as the James Bay Project, in Quebec spurred rapid population growth and the need for housing and infrastructure, which contributed to the expansion of the construction industry in nearby villages and the growth of public services, driving business activity (Senécal and Égré 1999). However, as with other projects involving the displacement of people, there are always positive and negative aspects because, despite a marked improvement in the quality of life in the new location, several dozen people refuse to leave the premises and move, especially senior citizens who are forced to move due to the construction of the dam where they live. These people seem to experience a sense of loss, which may result in health problems or depression (Senécal and Égré 1999).

Another affected community in the Amazon region is the indigenous population, which, in addition to removal, undergoes the process of loss of indigenous culture. During the construction of the Lajeado hydroelectric plant in the state of Tocantins in northern Brazil from 1996 to 2001, there was an indigenous environmental compensation program to mitigate the social and environmental impacts of construction on the 3,000 indigenous people from the Xerente tribe, who were located a few kilometres downstream of the dam. Although there was a mitigation program, the history of indigenous people with so-called "non-indigenous" people has repeatedly been marked by violence and the struggle for land since the time of missionaries, prospectors, and settlers, causing great concern among the heads of tribes who were led to believe in the government programs which announced the advantage of the hydroelectric for getting progress and they had to accept it. In this sense, it caused a great migration of indigenous peoples (Hanna et al. 2016; de Paula 2000). This clearly shows the importance of analyzing cultural and social aspects when addressing any project. Moreover, it is reported in a recent study, that the indigenous chief knew the undesirable side effects that the proximity of the dam construction would bring to his people, for example, the increase in prostitution, alcoholism, the arrival of new diseases, the invasion of Xerente land due to the proximity to the construction site, and urban expansion, bringing associated impacts such as roads and noise (Hanna et al. 2016).

Other impacts can be noted in the urban population due to the rapid progress of the city and the increase in the population over a short period of time. According to Rocha (2014) and Cruz (2010), rapid population growth causes unplanned land occupation, which results in the volatility of real estate values and the loss of cultural heritage, with the degradation of local history in contrast to development (Cruz and Silva, 2010; Rocha, 2014).

Urban development creates a need for the State and municipalities to expand infrastructure to meet the burden on health, transportation, education, and sanitation systems generated by the population growth (Cruz and Silva 2010; Franco and Feitosa 2013). Due to the large inflow of workers to the construction site, it is common for the basic sanitation infrastructure to be absent or poor, particularly in developing countries, hindering personal hygiene actions and contributing to outbreaks of diseases that are transmitted by poor sanitation, such as diarrhea and cholera (Renshaw et al. 1998). The inflow of workers is one of the factors that is felt the most by the local population and was also found in a study on the hydroelectric plant of Lajeado in the state of Tocantins in northern Brazil. The city of Lajeado was full of "people from the outside"; according to anecdotal reports at the time, the city had doubled in population (Araújo 2003). Next to this plant, the city of Porto Nacional was also affected by the construction of the dam, starting with the flooding of an old and famous beach and sections of a traditional avenue that had mansions owned by old families in the city. Due to submersion by the dam, more than 50 of these mansions had to be demolished. The natural beach was often visited by tourists from various regions of the country and generated a significant income for the city (Araújo 2003). The year after the construction of the dam, there was the inauguration of a tourist complex on the banks of the dam, including a new avenue, sports courts, a go-kart racetrack, and an artificial beach, to reduce the impact generated by the loss of tourism and to boost new tourism (Araújo 2003). Unfortunately, it was reported that, a few months after the opening of the tourist complex, the water from the dam was of poor quality and the beach needed to be interdicted to take appropriate action (Araújo 2003); thus, there was a decrease in tourism, which was an important source of income, in the region due to poor infrastructure and sanitation.

During the construction of the Jirau and Santo Antônio hydroelectric dams, there was also an STD increase among the regional population, which is very worrying due to the proximity of the plants to the urban area of the state capital. Prevention and awareness campaigns about STDs are an alternative suggested by several authors (Renshaw et al. 1998) because these cases overwhelm the local health service and reduce the population's quality of life.

The change in the population's lifestyle caused by urbanization and the increase in population is also a reflection of increased income. On one hand, increased income may allow access to better health services, however, on the other hand, it may have permitted greater access to the consumption of alcohol, drugs, and prostitution, leading to violence and social exclusion and resulting in direct health effects among the population (Queiroz and Motta-Veiga 2012). Construction workers are a vulnerable community because they often live apart from their sexual partners, but they have a sufficient income to pay for sex workers. In this study, there was an increased rate of STDs in areas where construction sites are installed, and this event was also observed in the study by Renshaw et al (1998), who identified a gonorrhea outbreak during the construction of the Turkwel Gorge hydroelectric plant in Kenya.

The construction of a dam has the effect of submerging both wetlands and dry areas and may include rivers, lakes, and nearby towns. In a study after the construction of the Rosal plant in Brazil, it was reported that the most significant impact during the construction phase was the increase in temporary residents due to the influx of workers. The increased population involved the risk of introducing infectious agents, in addition to resulting in increased disturbances in the environment, waste production, and wastewater. In the operational phase of the plant, the authors suggest that the greatest impact was the formation of the lake and the departure of residents and workers from the area (Rezende 2009). The migration of large numbers of workers into the region, the displacement of local residents, and the change in flora and fauna are the main factors for the loss of local culture and identity, which may result in a wide range of social and environmental impacts on communities, such as intra-group conflicts and changes in agricultural practices and diets (Hanna et al 2016).

According to Alves and Justo (2011), the change in the water flow rate and riverbed flooding significantly alter fishing activity and the life of the riparian community, who are often completely dependent on this activity (Alves and Justo 2011). Changes in the physical environment trigger a higher exposure to heavy metals, especially mercury. This element has high natural concentrations in the soil, which are absorbed by the population when using the water and fishing resources for their needs (Lacerda and Malm 2008, Almeida et al. 2005). According to the WHO, the maximum allowed concentration of mercury is 50 parts per million (ppm) in water, and in the Amazon region, the riparian population has a concentration of 70 ppm in their urine, creating a health risk of mercury poisoning (Luca, 2012).

The fear of intoxication can cause changes in the diet, passing to the consumption of industrialized products, related to the indices of diabetes and obesity. This change in eating habits has had an economic and cultural impact, as well as not providing a connection with culture and a connection with the land. In addition, the indigenous population presents less life expectancy and face risks of obesity and chronic diseases (Queiroz and Motta-Veiga, 2012).

With urban development, there is also an increase in the vehicle fleet to meet the population's needs. However, this increase contributes to air pollution, with an increase in cardiorespiratory diseases in the population, which are commonly associated with air pollution (Abe and Miraglia 2016; Saldiva et al. 1995; Veronez et al. 2012). Dwellings near roads or highways may also cause health problems related to air pollution. A recent study in Beijing suggests that long-term exposure to air pollution related to vehicle traffic on major roads in Beijing is associated with lower lung function, airway acidification, and a higher prevalence of chronic cough (Hu et al., 2016).

Other illnesses are also identified, such as the increase in obesity caused by the change in eating habits due to the increased consumption of processed foods and the reduction of physical activity, which alters the previous nutritional behaviour. Another factor that causes correlated diseases is the stress caused by vehicular traffic (Ferreira et al., 2013).

The changes not only impact the riparian population but also reach the entire population of the city of Porto Velho in the state of Rondônia and in other states in the Amazon region; that is, they have cross-boundary impacts (Marengo, 2008)

For example, in the case of air pollution, the contamination plume can be carried by the wind to other areas beyond the site where it was generated, damaging health with diseases associated with air pollution or causing acid rain that deteriorates property. Another negative impact caused by air pollution is the emission of greenhouse gases, which result in the destruction of the earth's ozone layer, raising the planet's temperature and contributing to drought in places such as the Amazon basin, the melting of the polar ice caps, and even the destruction of the planet's biodiversity (Ehrmann and Stinson, 1994; IPCC, 2014).

The diagram network impacts elaboration at the national or international level will be of great value to enable preventive or mitigating actions to be taken before a change in public health resulting from an environmental impact. The actors engaged in the environmental licensing process in Brazil have the perception that health is simply the absence of disease, and the treatment of health in the EIA/RIMA is sometimes limited to an inventory of the health services infrastructure in the enterprise's area of influence (Brasil, 2014). In spite of the institutionalization and obligatory nature of the EIA-EIR to have meant a milestone in the evolution of Brazilian environmentalism (Silveira and Neto, 2014), it is a fact that the inclusion of the evaluation of health effects in the environmental licensing process is lacking. There is no regulation of any specific health impact assessment tool for the environmental licensing process in Brazil (Silveira and Neto, 2014).Negligence with the health effects of the population occurs relatively frequently, since the only legalized mechanisms of health participation in the environmental licensing process is the assessment of malarious potential in malaria endemic regions (mainly the Amazon region) (Barbosa et al., 2012, CONAMA, 2001, Katsuragawaet al., 2009, Silveiraet al., 2012, SVS/MS, 2006). For other health determinants, there are no specific legislation or directives articulated with Brazilian environmental licensing, as opposed to evaluations in developed countries that consider various social and health aspects in large enterprises.

Stinson (1994) expresses concern over the potential impacts of environmental degradation on human health, indicating the need to increase environmental awareness and unify various parts and sectors of society that analyze environmental risks differently and therefore observe differences regarding the effects on human health (Ehrmann and Stinson 1994). Thus, it is considered that the applicability of this model will be a key point for Brazilian public health, which lacks information or studies that show the influence of actions, projects, or programs in the area of health. This model will serve as a basis for the Unified Health System (Sistema Único de Saúde - SUS) in its actions and improve the decision-making process of the managers of regional health systems.

Motta-Veiga (2012) states that the effects of the implementation of hydroelectric plants in Brazil have been the focus of many discussions due to the size of their impacts. The large scale of the Jirau and Santo Antônio hydroelectric projects provokes the displacement of workers from other localities. However, because this intensive use of labor is temporary, it does not provide permanent employability, that is, as soon as the work get concluded, there will be a vertiginous growth of unemployment and definitive interference in the local social, environmental and economic dynamics (de Souza Moret and Guerra, 2009). However, the approaches found in the literature show an isolated view, such as only environmental or social impacts, without appropriately including the health issue. Therefore, we can appreciate and understand the importance of creating the network of aspects and impacts to analyze the interaction of sectors and stakeholders (Queiroz and Motta-Veiga 2012).

The proposed model supports the creation of mitigation actions and even remediation actions in health so that an increase in morbidity and mortality resulting from the development of the state of Rondônia can be avoided. This promotes the movement of a state's economy with positive impacts regarding sustainable development and negative impacts with regard to health, which has been estimated to date.

The impacts of the installation of the hydroelectric dam can be positive with regard to local and national development in terms of energy availability and a consequent change in the quality of life of this population. However, the development can introduce increased costs in the health system (primary, secondary, and tertiary, included social and mental costs). Thus, one can observe the impact on health, which, despite being a sector that is highly affected, is often overlooked in projects of large enterprises. The construction of the hydroelectric dams on the Madeira River will add new social and economic plots in the Rondônia territory. The implementation of transport and electric energy infrastructures in the Brazilian Amazon has been marked by major impacts due to the environment and have assigned new functions and forms of organization in the territory. In this way, hydroelectric plants constitute a structural element, generating new arrangements, revealing the political character and the power use in the territory, considering that its construction is to meet a demand external to the Amazon region (Cavalcanteet al., 2011).

The balancing of ecological needs with demands of industries and urban centers can be helped with certain technical expertise, but it is largely a contest between powerful political forces and the mute but fundamental needs for sustaining life on our planet (Jobin, 1999). It is necessary to consider the health opportunities, managing and mitigating the social conflicts. The cost of a dam is usually stated in terms of the money spent to build the infrastructure and carry out necessary preparatory tasks such as viability studies and resettlement. However, the opportunity cost of sacrificing the land use that would have occupied the site had it not been used for a reservoir should also be part of the decision when a dam-building project is initiated (Fearnside, 2005). This study demonstrates the importance of a qualitative diagram that serves as a basis for more efficient quantitative analysis to assist the start of conducting a prospective and quantitative HIA. The evidence generated from studies such as this can support the analysis of likely impacts and can predict and mitigate future impacts. The diagram begins to articulate some of the non-environmental outcomes and impacts of dam-building that are important to consider. The Brazilian government needs to develop and adopt a credible institutional framework (Fearnside, 2006).

We are aware of the limitations of our methodological approach in terms of the coverage of impacts and a complete analysis of each different situation and location. The lack of national high quality studies to cover a detailed range of determinants of health on affected population lead us to offer an extensive bibliographic search to summarize the hydroelectric dams impacts and to highlight its relevance. Nevertheless, we are confident that we provide an adequate basis for enlarging the overview aspects/ impacts influencing a case study that can be replicated in other situations. We adopt this methodological approach to the evaluation of an environmental policy and its associated health effects and we are finding interesting and significant results. Moreover, this tool is promising with regard to both retrospective and prospective HIA studies.

Recommendations

Some recommendations derived from this qualitative HIA retrospective study should be addressed to stakeholders and decision-makers.. We summarize them as follows:

1. Dams have to be weighed against alternative energy projects in terms of environmental, social and health costs, sustainability and climate effects;
2. Perform a prospective and quantitative HIA study to predict and minimize the health impacts;
3. Obtain evidence from previous studies to serve as the basis for the probable impacts analysis;
4. Develop a monitoring program to be performed along with the construction, enabling interventions with focus on minimizing health impacts;
5. Consult stakeholders frequently, searching for changes in habits and in the health status that appear before the increase in demand for the health service;
6. Create a communication system with health authorities, the construction company and policy makers to emphasize all of the occurrences of alterations in the project and construction process.

Conclusion

The diagram network impacts elaboration has been useful as an important tool for assessing a broader view of direct and indirect impacts categories, serving as a basis for further evaluations and studies. International data are limited to adapt in a national scenario, however, bring together national and international data and evidences can possibility cover a range of effects, collaborating for the network construction of evidences and country´s environmental licensing system.

Brazil´s dam-building plans in Amazonia imply substantial environmental and social impacts and pose a challenge to the country´s environmental licensing system (Fearnside, 2006). We recommend a strategic planning in health impacts to avoid externalities, to prevent and reduce costs in the health system, and to obtain continuous improvement with investments lower than that planned.

Therefore, one can conclude that the implementation of hydroelectric dams has significant regional effects in social, environmental, and economic aspects and especially in the health sector. We suggest a more comprehensive analysis in all of these sectors in order to improve the national knowledge and the adoption of HIA model to mitigate the negative impacts and maximize the positive aspects on the environment and the population.

Ethical approval: This article does not contain any studies with human participants performed by any of the authors.

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Chronicles of Health Impact Assessment Vol. 3 Issue 1 (2018) DOI: 10.18060/21777