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Peer-reviewed version available at Environments 2018, 5, ; doi:10.3390/environments5010014

Article

Analysis of future land use changes and water availability in the Nicaraguan Southwest as a result of the construction of the Nicaragua Interoceanic Canal

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Abstract: Nicaragua is preparing the construction of an interoceanic canal that will be the longest and largest canal on earth. An environmental and social impact assessment has been published in 2014 supporting a general viability of the canal. Nonetheless, several scientist and societal actors raised serious concerns regarding the social, economic and ecological sustainability. Despite an open dispute within the Nicaraguan society, no independent, transparent and scientifically sound assessment has been carried out. Only the environmental and social impact assessment, charged by the canal constructor, has so far been realized. The aim of this study is to contribute to an open scientific debate through an objective and independent quantification of land use and hydrological impacts. This article presents a transparently documented and comprehensible impact assessment investigation of the West Canal Segment of the Nicaragua Canal. Based on publically available data and scientifically sound and recognized methods land use, hydrological (water availability) and socio-economic impacts (streets, population) are described, quantified and compared with official declarations in the impact assessment. While some results support official declarations other do not. The number of affected population and the water use of the Brito Lock resulted much higher in this study, for instance. Hence, society and water availability could be affected much higher than estimated in the impact assessment.

Keywords: Interoceanic Canal; Nicaragua; environmental impact; water availability; land use classification

1. Introduction

Until today, there have been numerous attempts to build a canal through Nicaragua and different routes to cross the Atlantic part of the country as well as different transport media (e.g. a "dry" canal using railways) have been proposed. The Sandinista government under president Daniel Ortega once again picked up the plans to build an interoceanic canal in 2012 and achieved the passing of a special law for its construction (Law No. 840) by the National Assembly of Nicaragua [1]. The law defines a construction time of 15 years and an economic cost of 40 billion US-$. With Law No. 840 Nicaragua's National Assembly ratified an exclusive agreement between the Government of Nicaragua and the HKND Group to develop the Nicaragua Canal in June 2013. Thereby the HKND Group obtained the concession to build the Canal including the exploitation right for at least 50 years with possible prorogation. The concession includes the construction of two deep-sea harbors, two airports, free trading Zones and an oil refinery among others.

Essentially, the construction of the Canal is economically motivated, targeting container traffic and bulk carriers that are too large to fit through the expanded Panama Canal. However, geopolitical reasons may add too as other political powers look for alternatives to the Panama Canal. While economic reasons favor the construction of a canal, environmentalist have raised severe concerns by drawing attention to the loss of important ecosystems and rare species. Nevertheless, also among the Nicaraguan population the possible construction of a canal is understood as a feasible way out of poverty for the country [2].

With 5,000 million m³ of sediment excavation, the project will be by five times the largest earth moving operation in human history [3]. The Canal will be longer, deeper and wider than any other interoceanic canal and result in a permanent connection of the Atlantic and Pacific Ocean via the second largest freshwater lake of Latin America and the biggest freshwater reserve of Central America (Figure 1). Thus, endangering water supply of Nicaragua as well as other countries of the region. Since the project will have strong impact on the country and the Central American region, there is an enormous public interest on possible consequences of its construction and a demand for an open debate.

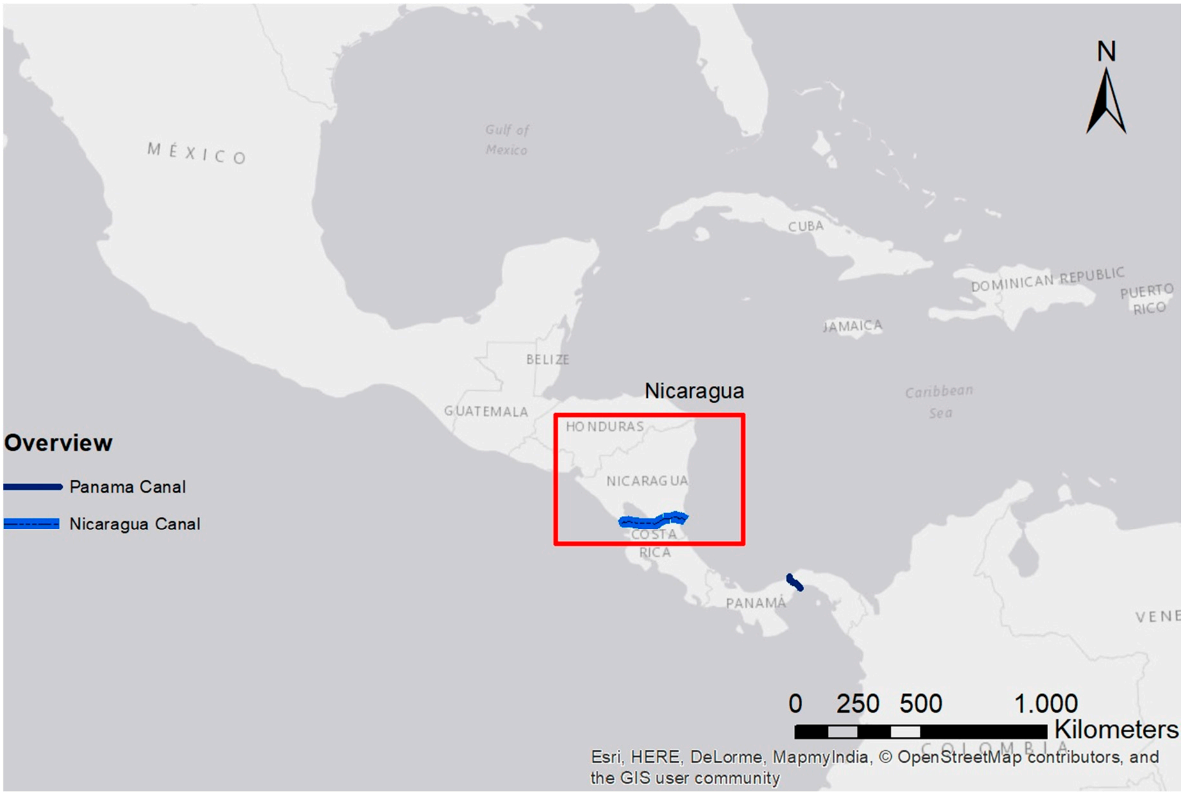

Figure 1. Overview interoceanic Canals of the Americas.

1.1. Deficits in the environmental impact study

The consulting company Environmental Resources Management (ERM) was engaged by the HKND-Group to perform the Environmental and Social Impact Assessment (ESIA) as principal planning basis for the construction of the interoceanic canal. Therefore, the importance of the ESIA results in the public and political decision making progress must not be underestimated. However, basic scientific principals are not met consistently. Data sources and quality are not revealed in most of the revised chapters nor is a description of the methods used, assumptions made and precision of results given. Moreover, there are several contradictions and discrepancies in the information provided in the ESIA. The version of the ESIA referred to in this publication was published in 2015

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and was downloaded from the HKND webpage (www.hknd-grouop.com) in April 2017. Nonetheless, the official declaration of the beginning of the canal construction dates to December 2014 [4], but since then only preparatory steps have been undertaken.

Several contradictions and discrepancies are highlighted in the following exemplarily. ERM presents data regarding actual land use in several sections of the ESIA. Among others, these include, the determination of soil potential (Section 5.3 + Appendix), biodiversity assessments (Section 5.9 + Appendix) and hydrologic modelling (Section 5.7 + Appendix). Nonetheless, sections are not consistent with regard to data sources, applied methods, interpretation (e.g. land use classes) and results. Differences are substantial and crucial for the following assessment of the potential environmental impact of the proposed construction. For instance, in section 5.3 an amount of 3% forest (Table 5.3.7, [3], date 2011) in the studied Canal Zone is determined, while in chapter 5.9 the result is 30% for the same area (Table 5.9.4, [3], date 2014). This results in a difference of approx. 6,500 ha forest, which at least partially is highly valuable subtropical dry forest [5]. Yet other results for land use classification can be found e.g. in table 5.13-43 and table 31 ([3]; Appendix GS-1).

Other examples regarding inconsistency of data and results can be found in the hydrological study. For the Rio Brito catchment varying amounts for precipitation, evapotranspiration, runoff and discharge are listed (Section 5.7 + Appendix RH-2), several of them contradictory. E.g. an exemplary dry year with 289 mm annual precipitation and an exemplary wet year of 1,423 mm annual precipitation. Nonetheless, an average year is quantified with 1,450 mm annual precipitation in the same catchment (Appendix RH-2).

Furthermore, discrepancies in sources of information exist. Results of the land use analysis in Chapter 5.9 are referenced to the source FUNDAR 2014b. However, in the list of references in Chapter 16 only the reference FUNDAR 2014 – Analisis comperativo de ecosistemas y cambio de uso del suelo … can be found. In Appendix BT-5 and BT-6, Volume 11, again FUNDAR 2014 is referenced, but with FUNDAR 2014: Biodiversity Technical Report…. This inhomogeneity of sources and quoting practice draws doubts on the retrieved information.

1.2. Aim and scope

Besides the unprecedented ecological and socio-economic impact of the canal construction, there has been very little investigation on it. Apart from comments, essays and opinion papers [6–11] only a general comparison with the Panama Canal [12] and an analysis on the canal's potential impact on international seaborne trade patterns [13] can be found in scientific literature. Hence, the aim of this article is to contribute to an open scientific debate through an objective and independent quantification of land use and hydrological impacts that will be set in context with the ESIA results. This will contribute to the knowledge of the Canal's impact on local populations as well as ecosystems and facilitate information for better decision making.

This publication addresses shortcomings of information provided by the HKND Group as stated in the ESIA concerning the water balance as well as doubts with regard to the extent of impacts on present land use (including population) voiced by the civil and scientific community. However, the following study is limited to the "West Canal", the part crossing the Isthmus of Rivas in the southwest of Nicaragua connecting the pacific coast with the Nicaragua Lake (Figure 2).

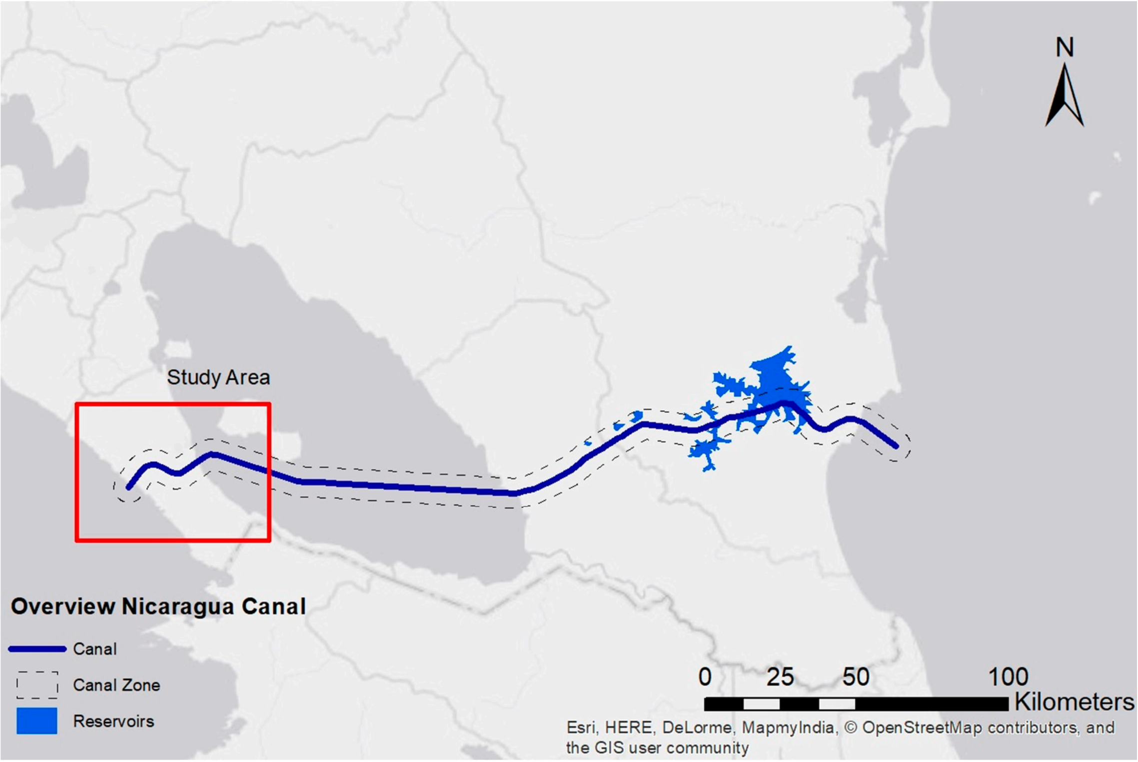

Figure 2. Overview of the planned Nicaragua Canal.

Specifically, this publication is responding the call of the panel of international scientists at the Independent International Workshop organized by the Academy of Sciences of Nicaragua in November 2015. At the workshop scientists asked for "…an independent expert committee to help review the recent environmental impact report [3] to ensure that the project delivers net economic, social, and ecological benefits to the country." and published a list of 15 major concerns regarding the ESIA [14].

2. Materials and Methods

This section introduces the data used and methods applied to determine the study area (Canal Route and Canal Zone), to carry out the land use and socio-economic impact analysis within the Canal Zone and to realize the hydrological analysis to quantify the available river discharge for lock operation. All data processing was realized with the geographical information system ESRI ArcGIS 10.1. In each subsection, the data sources and methodology applied in each comparative assessment of the ESIA are documented and differences to them stressed.

2.1. Study area

The West Canal Segment starts from the pacific coast at the Brito River Estuary, follows the course of the Brito River, crosses the watershed divide and then follows the Las Lajas River Valley to the Nicaragua Lake (Figure 3). The Canal will connect the Brito and the Las Lajas River Valleys through two sections joined by the Brito Lock to surpass the water table difference from sea level to the water level of the Nicaragua Lake. The Canal Section from the Pacific coast to the Brito Lock will have a length of 12.5 km; the section from the Brito Lock to the Nicaragua Lake has a planned length of 13.4 km. The minimum depth is 26.9 m and minimum bottom width is 230 m. Moreover, the Canal Construction will require dredging of marine sediments along 1.7 km at the entrance of the Canal on the Pacific Coast [3].

The future Canal Zone is situated in the department of Rivas with the capital city of Rivas being the most populated settlement of the department. The Canal Zone is dominated by scattered human settlements and agricultural land use.

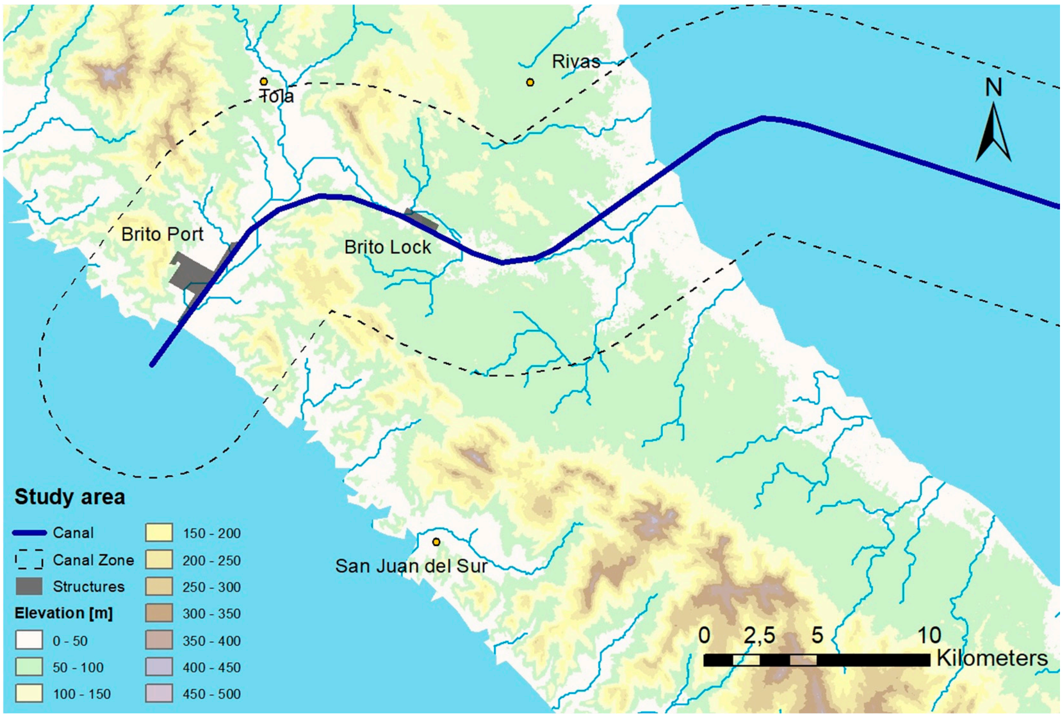

Figure 3. West Canal Segment of the planned Nicaragua Canal (Study area).

According to the HKND Group, several Canal Routes for the West Canal Segment were considered. The proposed one is supposed to have the least impact on people who would need to be resettled, avoids the Nahoa indigenous territory, reduces potential seismic risks and possibly reduces the construction costs [3]. However, the route is the only one crossing the biologically important natural reserve "Marina Isla La Anciana", which includes the mangroves of the Brito River Estuary. This approximately 1,460 ha large area is known for its high diversity of macro fauna, which has only been studied partly so far [5]. E.g., the red crab is an endemic species of this habitat, which has not been reported elsewhere in the country [5]. The Nicaraguan Environmental Ministry has proposed the reserve as priority area for marine conservation due to the abundant presence of corals. Furthermore, the studied Canal Zone includes tropical deciduous dry forest ecosystems being the ecologically most valuable connected habitat of the West Canal Segment. The Brito River Estuary and the dry forest ecosystems are important foraging, breeding and resting areas for many resident and migratory wildlife species as well as a nursery habitat for different kinds of sea life. Moreover, for rural communities, wildlife species like iguanas, red deer or olive ridley and hawksbill sea turtles are important sources of complimentary nutrition [5]. However, the sea turtle species are on then Red List as critically endangered species.

2.2. Land use analysis in the canal zone

A comprehensive understanding of land use changes is crucial for any profound evaluation of the proposed project. It allows quantifying valuable ecosystems and established uses affected by the Canal. Furthermore, land use is an important information to model the water balance of the project area in order to estimate water availability for future lock operation.

A way to gather land use information for wide areas is by satellite remote sensing – the analysis of reflected electromagnetic radiation of different wavelength to obtain spatial distributed surface information. The spectrum of wavelength used ranges from ~400 nm (blue light) to ~1 m (microwave radiation), with visible light from 400 nm (blue) to 750 nm (red). Radiation can pass the atmosphere in so called atmospheric windows – the corresponding wavelength are referred to as bands. The unique backscattering of a surface in multispectral scenes is called the spectral signature, which can

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be used to distinguish surface properties e.g. land use. To detect vegetation, red and infrared bands are commonly used (i.e. Normalized Differenced Vegetation Index (NDVI) for reference see e.g. [15]). More elaborated techniques are based on classification algorithms and/or reference areas.

For this study Landsat 7 ETM+ multispectral datasets were used, acquired from the USGS earth explorer web-platform. The spatial resolution of the visible and near infrared bands is 30 m. A temporal resolution of 2 pictures a day for each region is available. The spectral resolution provides 9 bands, with 3 bands in the visible spectra, three bands in the near infrared, two bands in the thermal infrared and one panchromatic band. Only cloud free pictures are a sensible input for a classification, as the detected wavelength cannot pass through clouds. As the study is located in tropical climate cloud free scenes are rare and a singular picture – date January 27, 2000 - was the basis for the classification.

In this study, the iterative self-organized (ISO) Cluster Routine and the Maximum Likelihood Classification provided by the ArcGIS Spatial Analyst Multivariate Toolset were used. The ISO-Cluster is an unsupervised procedure to generate land use classes, as there were no designated training areas. Instead, the expert knowledge of structures and properties of the study area helped to determine which combination of spectral bands and classes gave the most satisfying results. The ISO Cluster Classification uses a migrating means technique to generate land use classes from the multispectral signature of all pixels. A maximum likelihood algorithm is then used to sort each raster cell to the class with the highest probability [16].

The spatial resolution of the Landsat7 ETM+ data is not suitable to distinguish small-scale rural and urban structures (i.e. plots, roads, etc.). Therefore, five coarse scale classes of urban and rural characteristics were defined. Within the urban areas, two classes were differentiated, "urban and intensive agriculture" as well as "extensive agriculture". For the rural areas two classes were distinguished, "forest and thicket" and "rural open vegetated areas including grasslands". The fifth class represents "waterbodies". Best results were obtained with the bands 2, 3, 4 (green, red, infrared) of Landsat 7 ETM+.

In the ESIA multispectral satellite data, land use classifications obtained from the agricultural ministry of Nicaragua (MAGFOR) and field data were used. The remote sensing data are from the satellite program RapidEye Constellation from the year 2012 ([3], Appendix GS-1). The data have a spectral resolution of 5 bands (blue, green, red, red edge and infrared) and a spatial resolution up to 5 m. All footage and processed data obtained by RapidEye can be acquired commercially from Planet labs Germany [17]. Data was provided by the former Gesellschaft für Technische Zusammenarbeit (GTZ) within the conditions of development work with the Nicaraguan Government ([3], Appendix GS-1).

For reference about the classification procedure of the ESIA only an internal workflow document written in Spanish can be found in Appendix GS-1 [3]. Information concerning the date and number of used satellite pictures is lacking as well as a description about how the spectral signatures were obtained. The classification is supposedly done by a supervised classification algorithm, which is based on the NDVI in some manner. A classification solely based on the NDVI cannot obtain a land use classification, if a single scene is used, as only the vegetation activity can be assessed not the type of vegetation.

The focus of the ESIA was clearly on soil potential regarding the altered land use after the construction of the Canal. However, questions about valuable ecosystems and agriculture are somewhat ignored with that perspective.

2.3. Socio-economic impacts

This study assesses two socio-economic impacts: population resettlement and interruption of the transportation network. Within the Canal Zone and nearby, people mainly live in small settlements in rural areas, with Tola representing the largest settlement (about 3,322 inhabitants in 2017) located in the northern part of the Canal Zone, which is directly affected by the canal construction [18,19]. To assess both topics appropriately, data from the Nicaraguan National Institute of Development (INIDE) from 2005 (last national census) was used in order to obtain information

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about the administrative divisions, population distribution and transportation network. For information about population growth, world development indicators from the World Bank database were used as well.

The calculation of the affected population in the ESIA is based on the independent Project's Draft Resettlement Action Plan (RAP) within the area of influence. This draft is dated January 2015 but it is not publically available. Table 8.1-11 of the ESIA presents settlements per Canal Segment being affected by the Canal Construction. However, neither this table nor any other includes the population number of each settlement or Canal Segment [3]. This hinders a precise comparison of the calculated population values per segment. Moreover, the ESIA does not present a quantified analysis of all affected roads and only mentions seven main roads, which according to their first construction plans, will be improved. The absence of a quantification of all affected roads within the Canal Zone again hinders the possibility of comparison.

2.3. Hydrological analysis, water availability for locks

The Digital Elevation Model (DEM) used for the hydrological analysis was obtained from the Shuttle Radar Topography Mission data (SRTM-3) recorded in February 2000 [20]. The mission used an interferometric synthetic aperture radar to measure elevation data nearly global. The dataset used was published in 2014 with a resolution of 1 arcsecond (30 m) and a accuracy of 16 m vertical and 20 m horizontal [21].

After DEM preprocessing, the stream network and catchments of the study area (hydrological properties) were determined and the Canal Course reconstructed. Only the directly affected catchments, which locally provide water for the operation of the Canal and Brito Locks were taken into account. These are the catchments of the Brito and Las Lajas Rivers (Figure 4). The natural course of the Canal follows the course of both main rivers. The artificial connection of the rivers for the Canal Course was chosen with the lowest slope possible.

ERM worked with topography (DEM) obtained from the Nicaraguan Institute of Territorial Studies (INETER) as well as the hydrological model "Gridded Surface Subsurface Hydrologic Analysis" [3]. Origin, date and resolution of this data is not documented.

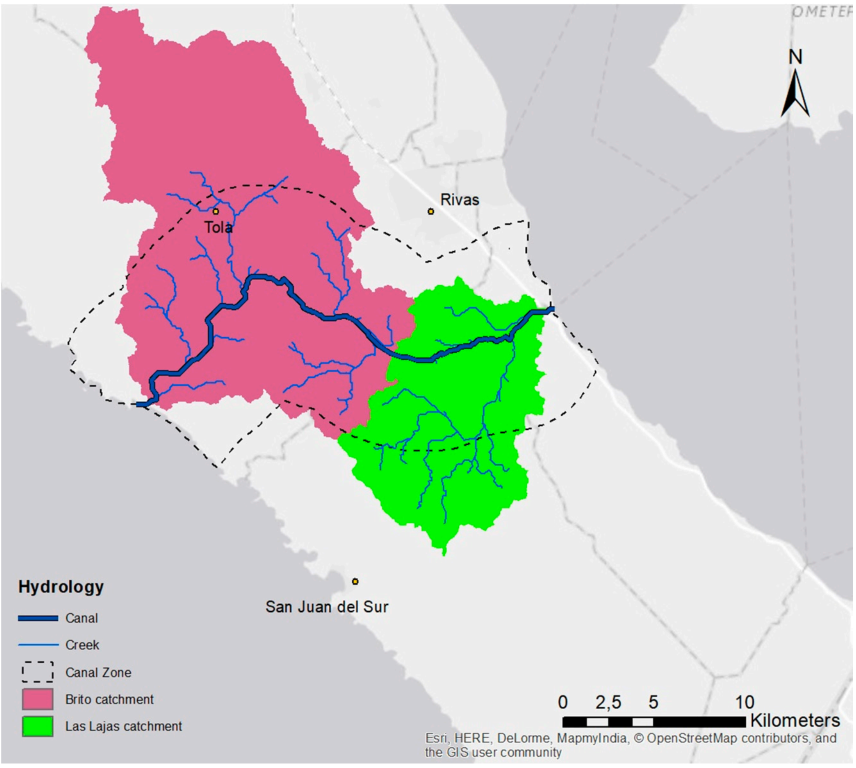

Figure 4. Representation of the catchments and the stream network supplying the canal.

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2.4. Discharge determination

For the determination of total runoff, three components should be considered: surface runoff, interflow and base flow. The surface runoff corresponds to the effective percentage of a precipitation event, which flows as an immediate runoff. The interflow flows into a water body with a short time delay (hours or days). Therefore, the interflow is considered part of the direct runoff on a monthly time scale. The base flow equals the amount of water that flows mainly from the groundwater into a water body.

Data of the rainfall gauging stations at the municipalities of Tola, Rivas and San Juan Del Sur provided by INETER is used to calculate an average of the rainy days per month. Thus, average rainfall per precipitation event within a given month is considered. The longtime mean annual precipitation is determined as sum of the monthly average precipitation and is 1,576 mm.

The effective monthly precipitation is calculated using the (former) U.S. Soil Conservation Service (SCS) Curve Number (CN) method [22], starting with the determination of CN value, which represents the storage capacity of a soil and the area-specific parameters like the moisture class, the soil type and the land use. These parameters are estimated based on the soil characteristics (soil type C and soil moisture class I) given by the ESIA ([3], Appendix GS-1).

Average monthly precipitation for the study on water balance was retrieved from WorldClim – Global Climate Data [23]. High-resolution (30 arcseconds ~ 1km resolution) climate data, e.g. average monthly and annual precipitation data, are obtainable worldwide. Among other, the databases of the Global Historical Climatology Network, FAO and R-Hydronet were used. Most records were acquired for 1950-2000. Error in mean monthly precipitation in general is below 10 mm, uncertainties are highest in the tropics and mountainous areas [24].

ERM obtained the streamflow and precipitation data from INETER, the climatological data from the National Climatic Data Center-NOAA and the soil type data from MAGFOR. Only two representative years (wet and dry) were modeled with the hydrological model of ERM. The Brito catchment was modeled for the years 2011 (wet year) and 2006 (dry year) and the Las Lajas catchment for the years 2005 and 2006 ([3], Appendix RH-2).

2.5. Water availability of the Brito locks

The HKND Group states that the locks on the Pacific and Atlantic side of the Canal will use most of the water from the artificial Lake Atlanta, which will accumulate the water from the catchment area of the Punta Gorda River. Lake Atlanta is planned on the Atlantic side of Nicaragua forming part of the East Canal [3]. However, it is unknown whether the Brito- and Las Lajas Catchments will provide the water for the Brito Locks on the Pacific side or whether water from Lake Atlanta will be necessary.

The Brito Lock consists of three successive chambers, which are used to overcome a height of about 10 m each to master the height difference between Pacific and the Nicaragua Lake (31 m). Each lock chamber has three water saving basins to reduce fresh water consumption of the lock by approximately 60% ([3], Appendix RH-12). For the calculation of the water volume needed to lift a vessel, the given dimensions from the HKND were used [3,25]. The year 2050 is used as reference year, in which 14 ships per day should cross the Canal (for comparison: 32 ships crossed the Panama Canal in year 2014; [26]). It is assumed that only one filling of the locks for the passage of two ships is required, which results in seven filling-draining processes of the chambers per day in 2050.

3. Results and Discussion

The presentation of results and the corresponding discussion follows the structure of section 2. The principle results are summarized and confronted with respective statements in the ESIA in Table 1.

302 **Table 1**. Analysis of results in comparison with published results from the ESIA

	Own Study	**ESIA** [3]	**% Difference**[1]	**Reference chapter ESIA** [3]
Land use				
Total area of Canal Zone	290.9 km^2	262.8 km^2	10.7 %	5.3.4.3
Forest	61.1 km^2	7.4 km^2	726.7 %	5.3.4.3
Near nature / Agriculture extensive	180.3 km^2	165.9 km^2	8.7 %	5.3.4.3
Urban/ Agriculture intensive	49.5 km^2	89.1 km^2	-44.4 %	5.3.4.3
Population	16,462	Not specified[2]	-	8.1.2.3
Hydrological Analysis				
Brito catchment area	271.4 km^2	268.2 km^2	1.0 %	App. RH-2 - 4.1.1
Las Lajas catchment area	106.8 km^2	98.3 km^2	8,6%	App. RH-2 - 4.2.1
Total catchment area	378.2 km^2	366.5 km^2	3,2%	App. RH-2 - 4.1 + 4.2
Long-term annual Precipitation	1,576 mm	1,463 mm[3]	7.7 %	App. RH-2 – 3.1
Long-term effective annual precipitation	515 mm	Not specified	-	-
Baseflow	79 mm	Not specified	-	-
Brito River discharge	5.1 m^3/s	4.6 m^3/s[4]	10.9 %	5.7.9.1
Las Lajas River discharge	2.0 m^3/s	~ 3 m^3/s[5]	-	App. RH-2 - 4.2.1
Total discharge	7.1 m^3/s	~ 7.6 m^3/s	-	-
Proportion of total discharge from total precipitation	38 %	45 %	- 15.5 %	-
Brito Locks (2050)				
Water demand	36.5 m^3/s	27.7 m^3/s	-31.8 %	App. RH-12 - 6

303

[1] Calculated as a relative difference with ((Own study – ESIA)/ESIA) as percentage

[2] Affected population not specified for the West Canal Segment, only an estimation of 30.000 people for the entire Canal and Canal Zone

[3] Weighted Average for total catchment area from values given in the referenced Appendix

[4] Extrapolated from measured discharge given in Table 5.7-23 (ESIA) at gauge Rio Brito

[5] Average from discharge wet year and discharge dry year in the referenced Appendix

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3.1. Study area

The Canal Route and associated Canal Zone elaborated in this study was constructed based on the natural course of the two river catchments. The differences compared to the planned Canal Course and Canal Zone by the HKND Group are negligible (compare Figure 3 and Figure 7). The derived catchments for this study are also very similar in form and size to the catchments documented in the official planning documents (Table 1). Therefore, the constructed Canal Course, Canal Zone and catchments represent a good basis for the following comparisons with official impact statements.

3.2. Land use analysis in the Canal Zone

The achieved results of the land use classification are presented in Table 1 and Figure 5. The Canal Zone including the 10 km buffer area has a total size of 291 km² according to our study. The total amount of residential and rural areas appears to be rather similar, while a clear change in land use patterns from east to west can be seen. The eastern part of the study with the coastal area of the Nicaragua Lake shows predominantly smaller urban structures with agricultural areas. The western part and pacific coast is mostly rural with several ecosystems of special value like the tropical dry forest and the mangrove areas. The transition between these main areas is rather abrupt and coincides with the watershed divide or the mountainous areas. The visual comparison and use of expert knowledge of the study area agree well with the obtained results within the possible accuracy. Additionally, some important structural features especially creeks can be identified well.

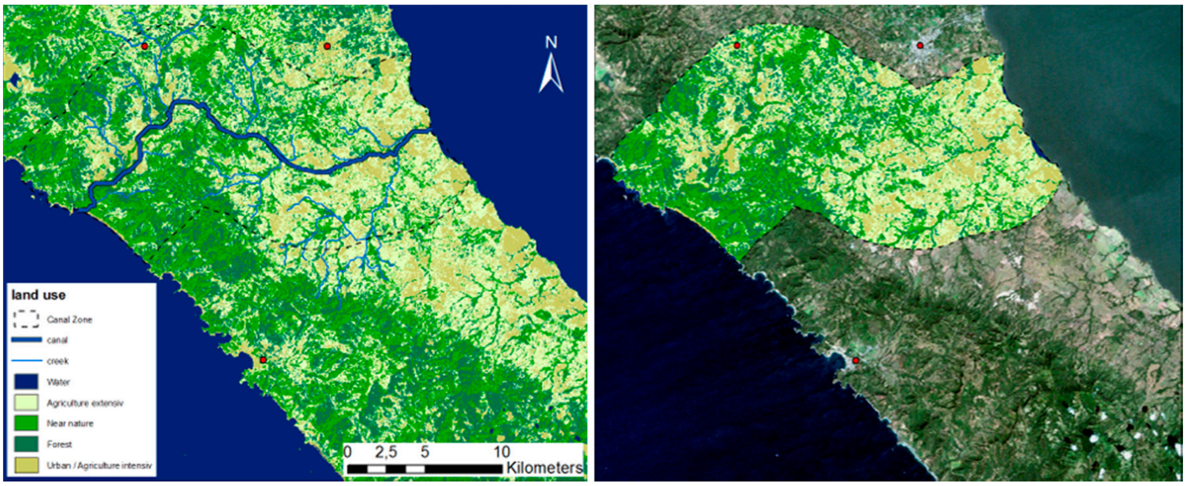

Figure 5. Results of land use classification in the western Canal zone, RGB-Image (Landsat 7-Data)

In the ESIA a total of ca. 16,400 ha extensive agriculture including grassland in the western part of the Canal Zone are calculated. 8,616 ha are assigned as crops in form of intensive agriculture. “Open and closed mixed leaved forest” and “dense urban areas” make up 744.2 ha and 0.5 ha respectively. A remarkable difference in assigned forest area is noticeable. In this study, several unsupervised classifications were run, with the chosen bands differing in the number of originally used classes and boundary conditions of the algorithm as each pixel of the datasets represents a variety of surface reflections. All classifications showed similar patterns, as shown in Figure 6, and resulted in no less than 10 % (~2,900 ha) forest and dense natural vegetation.

To validate the results a comparison with a multi-temporal, multispectral land use analysis provided by the former GTZ was performed [27]. The study accounts for approx. 1 % of mangrove forest, 8% of broadleaf forest and 20 % of thicket in the Canal Zone. This agrees well with our results. The mangrove forest equals an area of 290 ha compared to 103 ha in the ESIA (Table 5.9-3; [3]).

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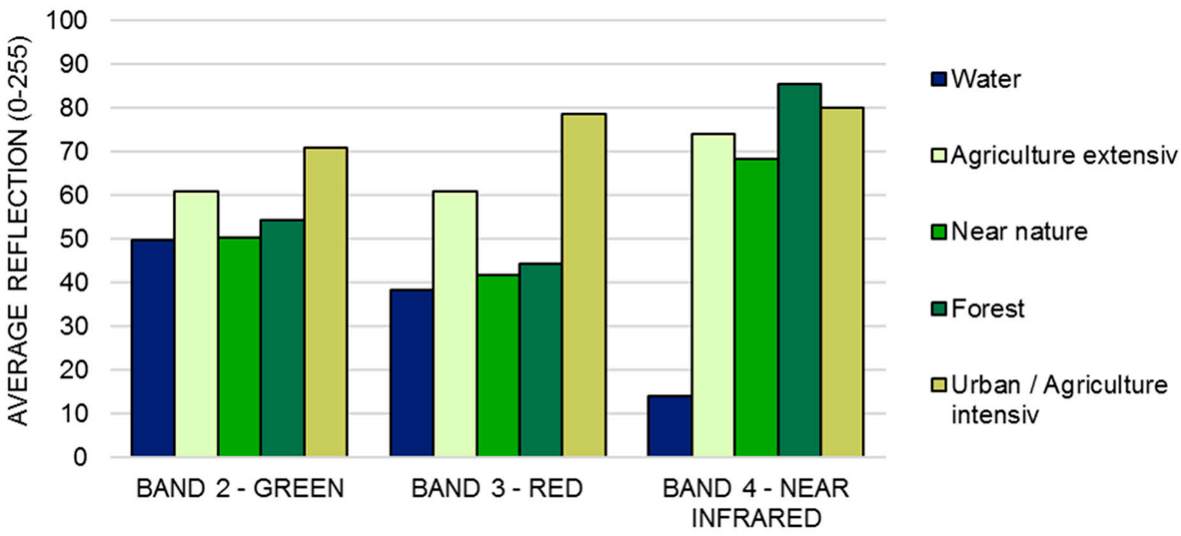

Figure 6. Average reflection of each land use class and wavelength

Figure 6 shows the spectral signature of each designated class. The signature differences among the land use classes are generally rather small yet clearly visible. The benefit of using the green band in addition to NDVI bands is obvious. Use of the blue band has generally little effect due to high scattering in the atmosphere.

The presented classification allows for a first approach in assessing the results presented by ERM, developing a robust method for land use classification in the Canal Zone and evaluating the affected usages in the Canal Zone. It establishes a baseline for further research. The quality of the classification suffices to identify problems in the conducted ESIA. It has become clear that the analysis of vulnerable ecosystems such as the dry forest or mangrove forest is yet to be assessed to clearly understand the impact of the proposed Canal.

3.3. Socio-economic impacts

The rural settlements directly affected by the Canal Zone (Figure 7) had a total population of approximately 14,072 people in 2005 [19]. With an averaged population growth in Nicaragua between 2005 and 2017 of 1.2% per year, the population in 2017 is estimated to 16,462 people [18,19].

ERM identifies in the ESIA 7,210 households i.e. 30,000 people, who will be temporarily or permanently affected by the Canal construction. This value corresponds to the entire Canal (including West and East Canal Segments) [3].

The resettlement of the people will result in cultural, economic and political consequences, such as the loss of identity, private and family life, the disintegration of large families and other social relationships, that provide stability. The inhabitants will also lose their usual sources of income and will have to address unknown tasks. Additionally, the division of the entire department of Rivas and its municipalities will cause difficulties and changes in the political management of these administrative units.

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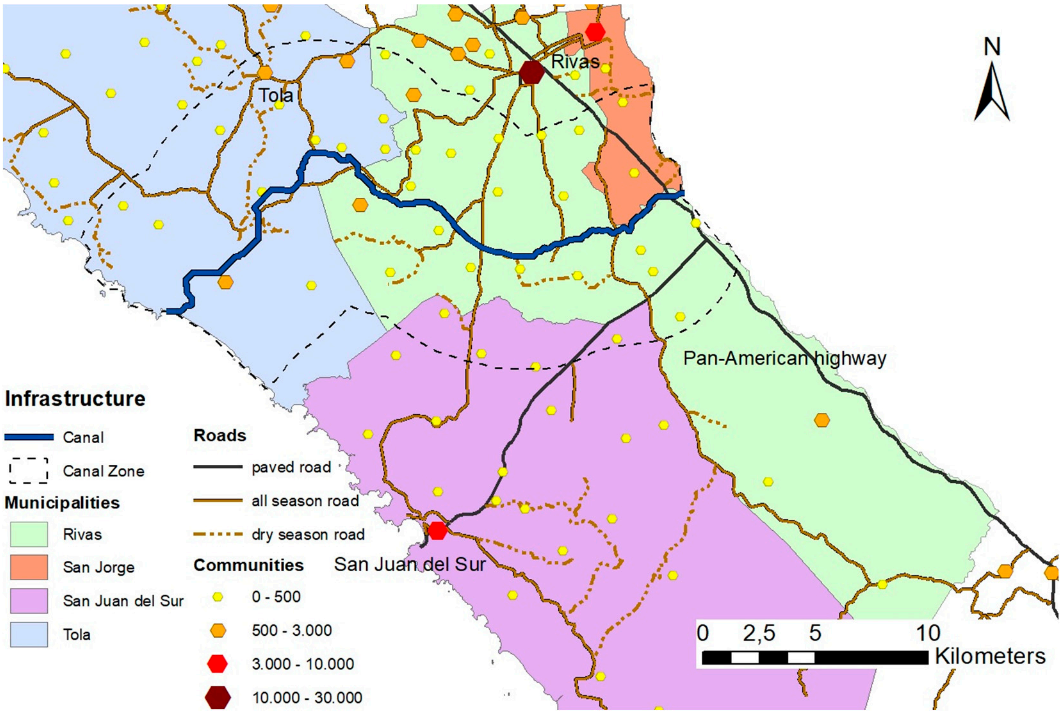

Figure 7. Affected communities and roads through the canal construction [19]

The road network has a total length of approximately 175.8 km. From which many are dry season roads (56.2 km), eleven are all season roads (97.1 km) and two are paved roads (22.5 km), with the Panamerican Highway being the economically most important road in this area, which will be at least temporarily interrupted by the Canal (Figure 7).

3.4. Hydrological analysis

The hydrological analysis starts with the calculation of the catchment size of the Brito River (271.4 km²) with its discharge at the Pacific and the catchment of the Las Lajas River, which flows into the Lake Nicaragua (106.8 km²) (Figure 4). Together both catchments have a total area of 378 km². Additionally, the Canal Course with the artificial connection between the Brito River and the Las Lajas River with a length of 35.1 km was constructed. The difference to the catchments areas calculated by ERM as well as the Canal Course planned by HKND are small and therefore negligible (Table 1).

3.5. Discharge determination

Applying the SCS method an effective annual precipitation of 514.6 mm is calculated, which corresponds to 33% of total precipitation from surface runoff. Romero Callo [28] analyzed the hydrological properties of the Gil Gonzalez catchment in the department of Rivas, working with data from 1970-2009 and calculated with a mean annual precipitation of 1,051 mm a mean runoff coefficient of 33%. These two independent studies seem to support each other well.

Due to geological formations, the underground water storage capacity in the study area is low. Thus, a retention of the base flow of 5 % of the precipitation from the previous month is assumed in accordance with field measurements and observations. This results in a base flow of 78.8 mm per year. The discharges of the Brito and the Las Lajas Rivers are respectively 5.1 m^3/s and 2.0 m^3/s. Together they form a total runoff of 7.1 m^3/s, which represents 38% of the total discharge from total precipitation (from surface runoff and base flow in form of stored precipitation). Figure 8 shows the monthly precipitation and base flow as well as the discharge of both catchments.

 doi:10.20944/preprints201709.0045.v1

Peer-reviewed version available at *Environments* **2018**, *5*, ; doi:10.3390/environments5010014

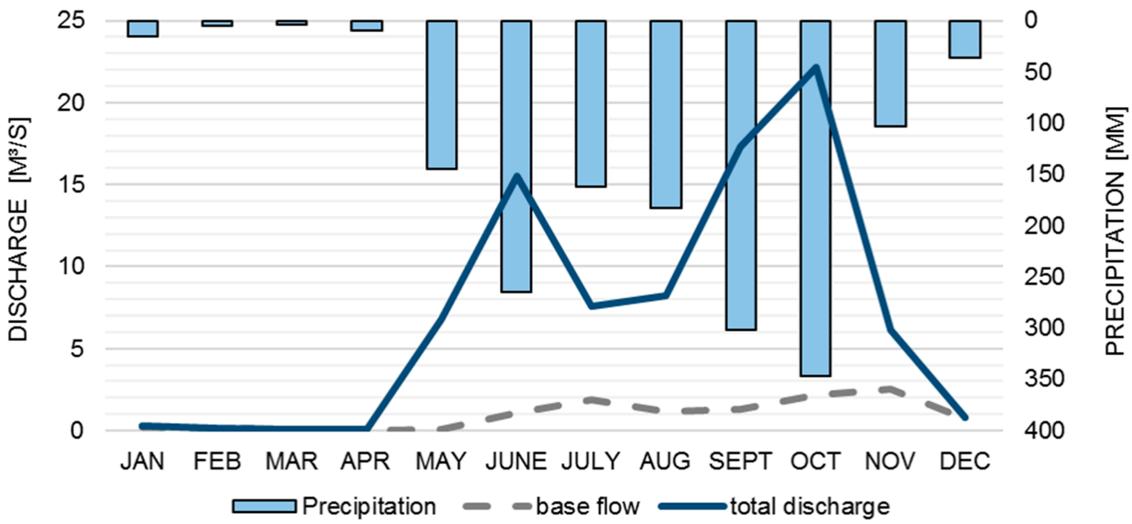

Figure 8. Long term average monthly precipitation (WorldClim), base flow and total discharge of Brito and Las Lajas catchment.

The hydrological model results presented in the ESIA (wet year) have a similar long-term annual precipitation (1,463 mm) and catchments discharge (4.6 m^3/s and ca. 3 m^3/s); the long-term effective annual precipitation as well as the base flow are not specified in the ESIA (Table 1).

3.6. Water availability for the Brito Locks

A water consumption of the Brito Locks for the year 2050 with a seven filling-draining process per day of approximately 91.2 m^3/s was calculated. If there actually are water savings of 60 %, the water consumption could be reduced to 54.7 m^3/s, thus, the total water demand of the chambers will be nearly 36.5 m^3/s (Table 1). However, water losses from the gate, evaporation and percolation are not considered in this calculation. Including these losses would lead to an even higher water demand.
The volume of water provided by Brito and Las Lajas catchments (7.1 m^3/s) could only meet 20 % of the water requirements of the Brito Locks (36.5 m^3/s) – assuming discharge would be evenly distributed over the year. Meeting the water requirements with excess water from the East Canal Segment is questioned. Among other major concerns regarding the ESIA, Covich et al. [14] criticize this part of the study severely because of its lack in long-term climate data monthly water budget and the lack of valid estimations concerning the Atlanta reservoir.

4. Conclusions

This article presents a transparently documented and comprehensible impact assessment study of the West Canal Segment of the Nicaragua Canal. Based on publically available data and scientifically sound and recognized methods, land use, hydrological (water availability) and socio-economic impacts (streets, population) were described, quantified and compared with official declarations in the ESIA. While some results support official declarations other do not. The water use of the Brito Lock was calculated much higher in this study, for instance. Moreover, our study reveals a lower proportion of total discharge from precipitation (effective rainfall) than stated in the ESIA. This leads to a lower discharge availability, which may become critical if future rainfall decreases. The number of affected population in the West Canal Zone, given its small proportion of the total Canal Zone, is high, but in absence of respective information in the ESIA not conclusively comparable. Hence, society and water availability could be affected much higher than estimated in the ESIA. With regard to land use our results identified much larger loses of forest and less loses of intensively used areas (urban / agriculture intensive). This implies a potentially higher ecological impact than stated in the ESIA.

However, comparisons with official declarations were difficult because neither the data sources nor the methodology is well documented in official reports (ESIA). This study was realized in order to elaborate scientifically based, transparent, understandable and reproducible information on possible impacts of the construction of the Nicaragua Canal to support decision-making.

Compared to the other canal segments, the West Canal has the largest amount of population affected, densest traffic network and the highest (agro-)economic activity. Therefore, the social and economic impacts are probably the most important concern here, while in the other canal segments environmental impacts on pristine ecosystems, higher biodiversity and on indigenous communities are more dominant. However, especially the Brito River Estuary and the remaining tropical dry-forest areas are unique and important ecosystem that need to be conserved.

Acknowledgments: We acknowledge support by the German Research Foundation and the Open Access Publishing Fund of Technische Universität Darmstadt. Further we want to express our gratitude to Michael Kissel for valuable comments on the manuscript.

Author Contributions: J.H. wrote on abstract, introduction and conclusions; J.H. contributed the material and methods summary as well as the results and discussion section with regard to the study area; A.R. contributed the material and methods summary as well as the results and discussion section with regard to the land use analysis in the canal zone; A.R. elaborated and designed the figures and tables; A.M. contributed the material and methods summary as well as the results and discussion section with regard to socio-economic impacts, hydrological analysis, discharge determination and the water demand for the Brito locks.

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

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