THE VALUE OF REAL AND VIRTUAL WATER IN THE PRODUCTION OF CONCRETE IN THE METROPOLITAN REGION OF BELÉM-PA, AMAZON, BRAZIL

O VALOR DA ÁGUA REAL E VIRTUAL NA PRODUÇÃO DE CONCRETO NA REGIÃO METROPOLITANA DE BELÉM-PA, AMAZÔNIA, BRASIL

EL VALOR DEL AGUA REAL Y VIRTUAL EN LA PRODUCCIÓN DE HORMIGÓN EN LA REGIÓN METROPOLITANA DE BELÉM-PA, AMAZONIA, BRASIL

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ABSTRACT

The virtual water can be defined as that which is embedded in products. Thus, water is present in civil construction in real and virtual forms. Real water is used in the extraction of raw materials, for manufacturing building materials and during the daily activities of buildings. Virtual water, on the other hand, is incorporated into the product. Assuming growth in concrete production and water scarcity concerns, this research proposed analysing the amounts, importance and economic values of real and virtual water as intrinsic parts of concrete. Data for the period from 2002 to 2019 were collected and analysed, both for Brazil and for the State of Pará. In this case, the values of the historical time series of per capita gross domestic products (GDP), cement and water prices were projected for the next ten years. In parallel, the procedure evaluated the amounts and prices of supplies used in the manufacture of one cubic metre of concrete, and consequently, the amount of real and virtual water present in the supplies also accounted for a one cubic metre quantity of concrete. By considering the amount of water in raw materials and the corresponding unit costs, the percentages of increase in the value of one cubic metre of concrete correspond to less than 1.14% for real water and 39.9% for virtual water. These price differences, although they exist, are currently not added to the final production price of concrete. Therefore, it is necessary to consider the amount of this natural resource as an inherent part of concrete, so that the value of water can effectively be perceived and approximated by the construction sector today and in the future.

KEYWORDS

Virtual water price; concrete price; gross domestic products; Amazon.

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RESUMO

A água virtual pode ser definida como aquela que está embutida nos produtos. Assim, a água está presente na construção civil de forma real e virtual. A água real é utilizada na extração de matérias-primas, na fabricação de materiais de construção e durante as atividades diárias das obras. A água virtual, por outro lado, é incorporada ao produto. Assumindo o crescimento da produção de concreto e as preocupações com a escassez de água, esta pesquisa se propôs a analisar as quantidades, importância e valores econômicos da água real e virtual como partes intrínsecas da fabricação de concreto. Foram coletados e analisados dados do período de 2002 a 2019, tanto para o Brasil quanto para o Estado do Pará. Neste caso, foram projetados os valores das séries históricas do produto interno bruto (PIB) per capita, dos preços do cimento e da água para os próximos dez anos. Paralelamente, o procedimento avaliou as quantidades e preços dos insumos utilizados na fabricação de um metro cúbico de concreto e, consequentemente, a quantidade de água real e virtual presente nos insumos também corresponderam a um metro cúbico de concreto. Considerando a quantidade de água nas matérias-primas e os respectivos custos unitários, as percentagens de valorização do metro cúbico de concreto correspondem a menos de 1,14% para a água real e 39,9% para a água virtual. Estas diferenças de preço, embora existam, atualmente não são adicionadas ao preço final de produção do concreto. Portanto, é necessário considerar a quantidade desse recurso natural como parte inerente do concreto, para que o valor da água possa ser efetivamente percebido e aproximado pelo setor da construção civil hoje e no futuro.

PALAVRAS-CHAVE

Preço da água virtual; preço do concreto; produto interno bruto; Amazônia.

RESUMEN

El agua virtual se puede definir como la que está incrustada en productos. Por lo tanto, el agua está presente en la construcción civil en formas reales y virtuales. El agua real se usa en la extracción de materias primas, para fabricar materiales de construcción y durante las actividades diarias de los edificios. El agua virtual, por otro lado, se incorpora al producto. Suponiendo el crecimiento en la producción de concreto y las preocupaciones de escasez de agua, esta investigación propuso analizar las cantidades, la importancia y los valores económicos del agua real y virtual como partes intrínsecas del concreto. Los datos para el período de 2002 a 2019 se recopilaron y analizaron, tanto para Brasil como para el estado de Pará. En este caso, los valores de la serie temporal histórica de productos nacionales brutos per cápita (PIB), los precios del cemento y el agua se proyectaron durante los próximos diez años. Paralelamente, el procedimiento evaluó las cantidades y precios de los suministros utilizados en la fabricación de un metro cúbico de concreto y, en consecuencia, la cantidad de agua real y virtual presente en los suministros también representaba una cantidad de concreto de un metro cúbico. Al considerar la cantidad de agua en las materias primas y los costos unitarios correspondientes, los porcentajes de aumento en el valor de un metro cúbico de concreto corresponden a menos de 1.14% para agua real y 39.9% para agua virtual. Estas diferencias de precios, aunque existen, actualmente no se agregan al precio de producción final del concreto. Por lo tanto, es necesario considerar la cantidad de este recurso natural como una parte inherente del concreto, de modo que el valor del agua puede ser percibido y aproximado de manera efectiva por el sector de la construcción hoy y en el futuro.

PALABRAS CLAVE

Precio de agua virtual; precio de concreto; producto interno bruto; Amazonía.

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1. INTRODUCTION

Consumption of water resources is increasing due to economic development, population growth and industrialization. The industrial economy sector consumes water for production processes, but some industries are beginning to feel the effects of the limited supplies of that natural resource (Mccormack et al. 2007; Dalin et al. 2012). From a neoclassical economics viewpoint, natural resources are considered to be common goods, with no price established in the market and, consequently, without economic value (Barros and Amin 2008). However, the evolution of capitalism has transformed water into a commodity where its value varies with each of its possible uses and destinations (Fracalanza 2005). Water, in this context, must be traded as a commodity that is sold and bought depending on market prices. As long as a human intervention is observed and there is a cost to transform the water "in natura" into drinking water or irrigation water, for instance, it ceases to be a common good and becomes an economic asset and an object of exchange and private appropriation (Barros and Amin 2008).

For example, El-Sadek (2011) analysed the concept of virtual water in agricultural products, as well as the market price of virtual water in those products. The author evaluated virtual water prices that were influenced geographically at global, regional, and local scales in Arab countries. These countries are strongly influenced by the value and availability of water resources. Although the author presented a well-structured methodology for calculating the value of virtual water, the study did not aim to propose a model for the value of virtual water. In this sense, the recent work of Graham et al. (2020) used a market equilibrium model for a global scenario that adopted the value of virtual water of agricultural products. Although most published works have been applied to agricultural products, some authors have conducted studies that accounted for water consumption in civil construction, especially for building construction. The work of Han et al. (2016) may be the first to evaluate consumption of virtual water during construction of a building complex in Beijing, although Meng et al. (2014) studied consumption of virtual water in civil construction, specifically for structures and external decorative works. The work of Han et al. (2016) adopted a hybrid method to determine the amount of virtual water by analysing all processes that were involved in construction and performed a water balance analysis for each process. The method quantified the virtual water inputs in each step of the construction process. The authors determined a total water consumption that was 24 times higher when virtual water was accounted for in the construction of a building complex and concluded by showing the importance of accounting for virtual water and its impact on civil construction costs. On the other hand, the work of Mack-Vergara and John (2017) evaluated some methods that have been used to account for water used in the concrete production industry. They applied a water life cycle inventory for concrete production. The inventory stage of the life cycle analysis (LCA) of concrete has often been used to account for water as a fundamental component of concrete in civil construction costs (Gursel et al. 2014).

In Brazil, many works have performed LCAs of concrete in civil construction scenarios (Borges et al. 2014). Accounting for water consumption in buildings using the LCA use stage was addressed by Proença and Ghisi (2010), who estimated the final destination of water for ten office buildings. The authors interviewed the occupants of the buildings to evaluate their daily water consumption during their labour activities. However, the authors did not develop an analysis of the amount of virtual water that was consumed during the construction process of the buildings. In the Brazilian Amazon region, State of Pará, and particularly in the Metropolitan Region of Belém (MRB), Belém (Lat: -1.45502 and Long: -48.5024) is the capital of Pará, sharp economic growth until 2015 has resulted in increased housing funding and has promoted opening of new construction companies. Consequently, concrete production has increased in the same period. Concrete is one of the most important elements of civil construction, with Portland cement used as a raw material, and can be manufactured at the construction site itself or in concrete plants.

Thus, the present work aimed to quantify real and virtual water as parts of concrete and how water will influence concrete costs over the next 10 years from 2020. A process analysis method was used to account for virtual water in concrete manufacturing, which is similar to published works (Arpke and Hutzler 2006; Cabeza et al. 2014). The water content in each of the raw materials accounted for one cubic metre of concrete. Additionally, the unit costs of raw materials were summed to form the concrete price and were then compared whether the water was accounted for or not. Additionally, for the period between 2008 and 2013, the work inferred the price variations for one cubic metre of concrete with 30 MPa of resistance that was produced in the MRB and afterwards forecasted concrete prices for the next decade, as influenced by water prices.

2. VIRTUAL WATER CONCEPT

The evolution of water resource management has resulted in a new way of understanding the importance of water through the concept of virtual water. The concept of virtual water is an that was expression coined by A. J. Allan, professor at the School of Oriental and African Studies at the University of London, during the 1990s, who showed how millions of litres of water are used in food production and are then marketed as an intrinsic part of these products (Lunardi and Figueiró 2012). The virtual water can also be defined as that which is embedded in products. Among these, commodities are responsible for a large amount of virtual water transfer (VWT). The VWT (Masud et al. 2019) is considered a parameter, which guides the global trade in water resources (Elena and Esther 2010). Since the conceptualization of virtual water (Allan 1998), the theme has aroused interest in various parts of the world (Chen and Chen 2013, da Silva et al. 2016, Chouchane et al. 2018).

The quantification of virtual water flow between regions is performed for different products, using different approaches and at different spatial scales (Vanham and Bidoglio 2013). Therefore, when a country or region exports or imports a product, water is exported or imported in virtual form (Hoekstra and Chapagain 2007). The exported or imported water footprint is often referred to as virtual water, where virtual water refers to the volume of water used to produce any given resource (Allan 1998). Water footprint or virtual water offer opportunities to assess the indirect impacts that the consumption of goods has on water resources that are geographically distant. The concept of water footprint determines the real and virtual water consumption of companies, people or even entire nations and these concepts have a considerable relationship (Hoekstra et al. 2009). The water footprint is defined as the volume of fresh water used to produce the goods. The water footprint is one of the components of the ecological footprint, which represents all the natural resources used in the production of a good (Gawel and Bernsen 2013).

Additionally, there are other influences on the amount of virtual water in a product, such as local environmental constraints, technological development, and the economic and social characteristics of the producing region (Carmo et al. 2007).

3. MATERIALS AND METHODS

3.1 Historical time series used for the study

Historical time series for the period from 2002 to 2019 were collected and analysed, both for Brazil and for the State of Pará. Data in the analysed time series contained the average monthly prices of Portland cement 32, gross domestic products (GDP) and per capita cement consumption amounts in Brazil. The objective of the analysis of the historical time series was to establish correlations between variables and make projections for the next ten years from 2020. The collected data are available in the database published by the Brazilian Chamber of the Construction Industry (CBIC 2019). The analysis methodology for the correlations and time series projections followed the steps:

a) Two historical time series of Brazil's GDP and GDP of the state of Pará were correlated to identify whether there was a direct dependence between the values of the two time series. This analysis served to confirm whether the state economy experienced the same variations as the national economy and consequently to define whether the national GDP could be used as an indicator for correlations with civil construction variables in the State of Pará.
b) The average monthly price of Portland cement 32 was analysed by using two historical time series, one for Brazil and the other for the state of Pará. The prices were then forecasted for the next 10 years from 2020. In this case, three possible scenarios were assumed. The first was a conservative scenario, in which prices were maintained at the current value for the present decade. The second scenario was one in which prices fell over the decade, with a tendency to have prices below the historical average. The third scenario assumed price resumption, with a tendency to recover to the value of the historical average.
c) Values of the historical time series of per capita cement consumption in Brazil were correlated with values of the time series of Brazilian per capita GDP. Thus, a correlation was obtained between the growth in per capita GDP as a function of per capita cement consumption.
d) Based on the historical time series of per capita GDP for the State of Pará, a polynomial regression estimated the growth function for the present decade. A simple polynomial function was obtained due to the linear behaviour of GDP over the previous 10 years.

3.2 Production stages of the concrete

The process analysis method was applied to the stages of the concrete cycle, from manufacturing to delivery at the construction site for the MRB case. Extraction of raw materials (i.e., fine and coarse aggregates), which are necessary for manufacturing concrete, mostly occurs at mines located in the northeastern region of the State of Pará. Upon arrival at a concrete plant, these materials are stored in separate containers. Cement is stored in vertical (closed) silos, while gravel and sand are stored in open horizontal silos; for this reason, control of sand moisture is important (in the laboratory) before mixing. This control is fundamental to quantify the amount of water present in the sand. If necessary, moisture levels can be corrected to maintain the appropriate proportions of water and cement in the concrete mix. Therefore, the concrete production stage can be used as a method to calculate water balance from the inputs and outputs to guarantee the correct moisture.

Weighing, mixing and measurement procedures are required during the stages of concrete production. Dry materials are weighed individually to ensure the proper quantities (measured by mass), and water and admixtures are then added (measured by volume). Currently, plasticizers are most commonly used as admixtures in concrete. The use of this type of admixture is mainly justified by the reduction in water consumption for concrete production (Weidmann et al. 2007). After weighing, the materials are fed into mixing truck drums and mixed at a velocity of two to five rotations per minute to avoid deposition. The truck drums store seven to ten cubic metre of concrete, and there is also a separate reservoir that is capable of storing 300 to 600 litres of water. During transport, the concrete loses some water by evaporation depending on air temperature and relative humidity. Therefore, to maintain concrete consistency, water can be added for maintenance of abatement.

As in previous stages, the last stage (delivery) is also an important step of the process to evaluate the amount of water in the concrete since on-site slump tests are performed to verify the consistency of fresh concrete. Slump tests are one factor that influences the final price per cubic metre of concrete. Thus, four stages were identified for the proper balance of real and virtual water as part of the concrete, namely, quantification of water in raw materials, water balance in manufacturing, quantification of water inputs during transportation, and quantification of water on delivery.

3.3 Real and virtual water in concrete

Throughout the concrete cycle stages, the amounts of water were analysed in each stage regarding inputs, outputs, flows, and transformations from real to virtual water (Fig. 01).

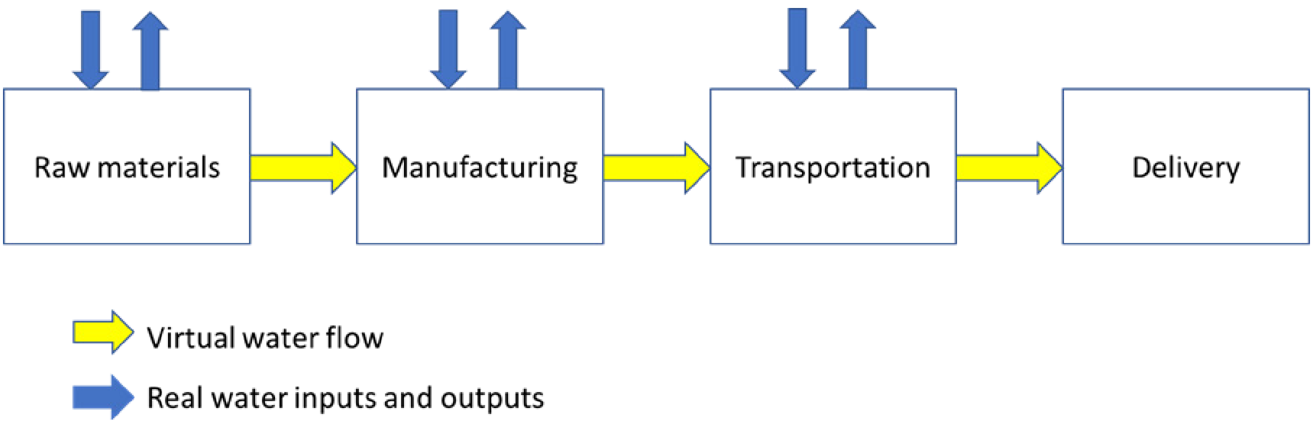

Figure 01: Real and virtual water stocks and flows during the cycle stages of concrete.
Source: Authors.

Real water is used during the extraction and treating raw materials (i.e., fine and coarse aggregates) processes. In mines, real water is transformed into virtual water once it is used in the treatment process of sand and aggregates, and raw materials are commercialized as building materials with virtual water inbuilt. In cement plants, the real water that is used in the process is transformed into virtual water, so the cement is also commercialized with virtual water.

The volume of virtual water in fine aggregates is 7.5 m3/ton, that in coarse aggregates is 6.25 m3/ton (ANA 2013), and that in cement is 0.1 m3/ton (ABCP 2020). To manufacture concrete, real water is dosed and added to the cement and forms a paste that joins the aggregates when hardened. The consistency of fresh concrete mostly depends on the amount of water per cubic metre that is added to the mixture (Tutikian and Helene 2011). Virtual water present in this stage is incorporated into the materials used for the volume of concrete. During concrete transport to the construction site, a small portion of real water can evaporate and be replaced from the reservoir of the concrete mixer truck. At this stage, real water is counted as an essential part of the concrete. The water used during concrete curing is counted in the delivery stage at the construction site.

For evaluations of the real and virtual water balances of the concrete cycle steps in the MRB, first, the amount of each component material needed to produce one cubic metre of concrete was quantified. Then, the amounts of real and virtual water present in each of the components were determined. The most commonly used coarse aggregate for concrete production in MRB is pebbles because it is extracted from mines located near the MRB. The amount of real water needed for concrete production depends on the resistance, fck, that is determined by dosage methods. For the present study, the dosage was based on the experimental work of Helene and Terzian (1995).

3.4 Calculation procedure

As described above, the concrete cycle stages for construction sites in the MRB were evaluated by determining the quantities of components for one cubic metre of concrete (Helene and Terzian 1995) and then by quantifying the real and virtual water present in each of the stages (Tutikian e Helene 2011). The calculation procedure is described by the flowchart shown in Fig. 2.

For the procedure described in the flowchart of Fig. 2, the values of the historical time series of per capita GDP were correlated to the values of per capita cement consumption, and a correlation function was obtained. The values of the historical time series of per capita GDP were also projected for the next ten years from 2020. Thus, the correlation function could project per capita consumption of cement for the present decade. The historical time series of cement and water prices also resulted in price projections for the next ten years. In parallel, the procedure evaluated the amounts and prices of supplies used in the manufacture of one cubic metre of concrete, and consequently, the amount of real and virtual water present in the supplies also accounted for a one cubic metre of concrete.

By knowing the price of one cubic metre of concrete and the total amount of real and virtual water present in one cubic metre of concrete, the value of one cubic metre of concrete was determined considering, or not, real and virtual water. The cost of water present in the concrete was determined based on the price determined by the MRB water concessionaire. A further analysis was performed to evaluate variations in concrete prices for the future based on projections of cement prices for the next 10 years from 2020. The influence of water prices was also evaluated on

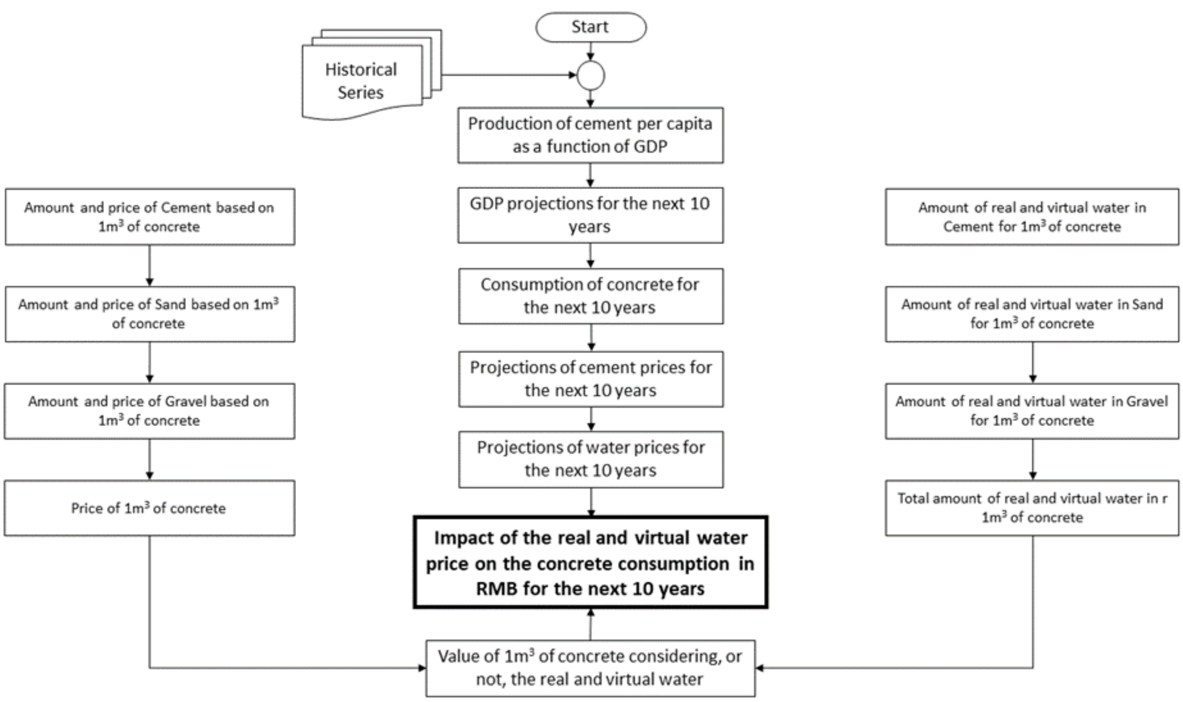

Figure 02: Flowchart for the calculation procedure of real and virtual water quantification and concrete price.
Source: Authors.

price variations in the previous 5 years and on price projections for the next 10 years.

4. RESULTS AND DISCUSSION

The correlation between the GDP (gross domestic products) of the state of Pará and GDP of Brazil was obtained from the historical time series available at the Brazilian Institute of Geography and Statistics - IBGE (2020) in local currency units (LCU), current Brazilian Reais, for the period from 2002 to 2019. Fig. 3 shows the correlation between the two GDPs and shows a consistent linear relationship.

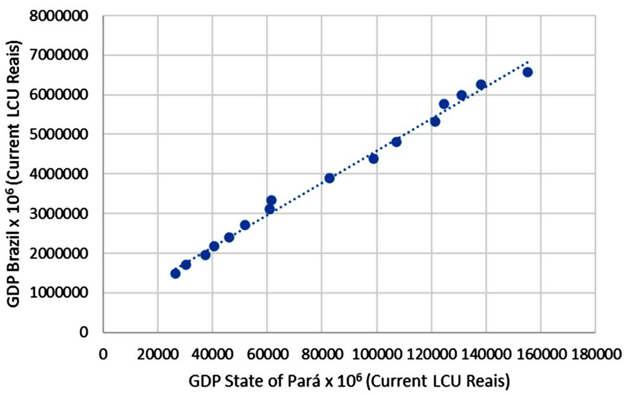

Figure 3: Correlation between GDP for the State of Pará and GDP for Brazil.
Source: Authors.

Thus, correlations and projections for the next 10 years from 2020 can be assumed to be a function of the Brazil GDP.

The historical time series of average monthly prices of Portland 32 cement for Brazil and for the state of Pará are presented in Fig. 4 in current American dollars. The blue line represents monthly prices for Brazil, the red line represents monthly prices for the state of Pará, and the black line represents the moving average of the price

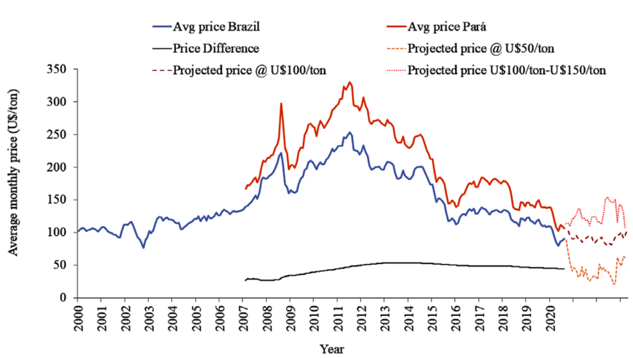

Figure 4: Average monthly prices of Portland 32 cement for Brazil and for the state of Pará
Source: Authors.

differences between the two time series. There is a direct relationship, with similar variations, between cement prices for the state of Pará and prices for Brazil.

It is worth noting that the last 10 points of the time series shown in Figure 5 represent projected values for the next 10 years from 2020 based on the exponential smoothing model. However, in Fig. 5, a second-degree polynomial regression (dotted line) was used to estimate the growth in per capita cement consumption as a function of per capita GDP. The function shows a tendency to consume 350 kg/inhabitant even for high per capita GDP values, exactly from R$ 40,000. The same exponential smoothing model was adopted to project the values of the historical time series of per capita GDP of the State of Pará (Figure 6) for the present decade. Figs. 5 and 6 were used together. Fig. 6 provides the per capita GDP for the state of Pará in function of the time (year) and Fig. 5 provides per capita cement consumption with the corresponding values of per capita GDP Brazil. It is known that GDP of the state of Pará can be represented by Brazil GDP (see the analysis of Fig. 3). Therefore, it was estimated through the Fig. 6, in 2020, that the GDP of Pará is approximately equal to R$20,000. Analyzing Fig. 5, this value corresponds to cement consumption per capita of approximately 276 kg/inhabitant. Thus, considering a population of 2.5 million inhabitants of the MRB (Metropolitan Region of Belém), the estimated total cement consumption was 690 thou-

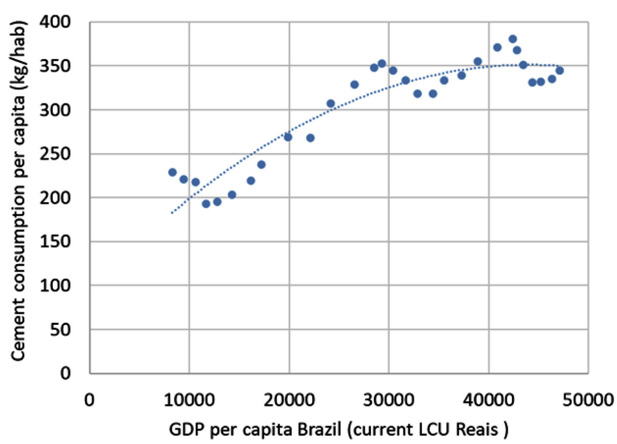

Figure 5: Correlation between per capita cement consumption and per capita GDP.
Source: Authors.

sand tons. Table 1 presents the results of quantifying the necessary components and their respective costs (R$) to manufacture one cubic metre of concrete.

The amounts of real and virtual water were not included in Table 1. Labour costs, loss of materials and administrative expenses were also not included. Table 2 shows

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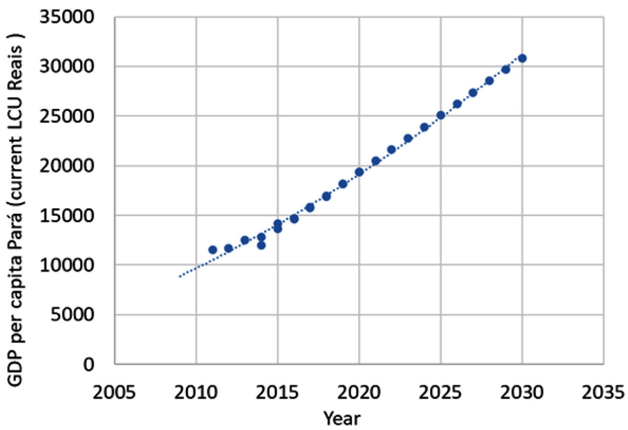

Figure 6: Historical time series and projected per capita GDP for the state of Pará.
Source: Authors.

Concrete Resistance	Cement		Sand		Pebble		TOTAL
f_{ck} (MPa)	Dosage (kg)	Price/50 kg (R$ 28.00)	Dosage (m^3)	Price/m^3 (R$ 35.00)	Dosage (m^3)	Price/m^3 (R$ 80.00)	Price/m^3 (R$)
25	292	R$ 163.52	0.651	R$ 22.79	0.607	R$ 48.56	R$ 234.87
30	317	R$ 177.52	0.649	R$ 22.72	0.618	R$ 49.44	R$ 249.68
35	344	R$ 192.64	0.64	R$ 22.40	0.626	R$ 50.08	R$ 265.12
40	365	R$ 204.40	0.598	R$ 20.93	0.632	R$ 50.56	R$ 275.89
45	387	R$ 216.72	0.625	R$ 21.88	0.637	R$ 50.96	R$ 289.56

Table 1: Components to manufacture one cubic metre of concrete.
Source: Authors.

Concrete Resistance	Cement		Sand		Pebble		Concrete	Total	
		(1)		(2)		(3)	(4)	(5)	(6)
f_{ck} (MPa)	Dosage (kg)	Virtual water (m^3)	Dosage (kg)	Virtual water (m^3)	Dosage (kg)	Virtual water (m^3)	Real water (m^3)	Virtual water (m^3)	Real water (m^3)
25	292	0.029	906	6.795	904	5.650	0.190	12.474	0.190
30	317	0.032	903	6.773	920	5.750	1.184	12.555	0.190
35	344	0.034	891	6.683	932	5.825	0.186	12.542	0.190
40	365	0.037	883	6.623	942	5.888	0.186	12.548	0.190
45	387	0.039	870	6.525	949	5.931	0.186	12.495	0.190

Table 2: Real and virtual water amounts in one cubic metre of concrete.
Source: Authors.

the amount of water that is present in one cubic metre of concrete in function of the resistance of the concrete (fck), which includes the virtual water present in cement (column 1), sand (column 2) and pebbles (column 3). The real water volume that is added to the mixture during the concrete production step is shown in column 4.

Column (5) is the sum of columns (1), (2) and (3) and represents the total volume of virtual water for one cubic metre of concrete. Column (6) shows the total volume of real water that is present in concrete. The importance of quantifying the virtual water volume in concrete is emphasized since it represents a much higher value than that of real water. According to the Brazilian Water Agency - ANA (2013), the industrial sector consumes the third largest share of water in the country based on withdrawal flows and the fourth largest share based on total water consumption. Brazilian industry has sought to balance water consumption by drilling wells and reusing water in industrial processes. Companies that produce concrete in the MRB do not pay for their water use and one of the reasons is that water is not inserted as a company liability since there is no charge for water consumption.

Table 3 presents concrete prices when considering real and virtual water as inherent components in function of the resistance of the concrete (fck). The calculated prices are based on the cost of water in the MRB that was esta-

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blished by the Water and Sanitation Company of the State of Pará. Table 3 also shows the price variations of one cubic metre of concrete when accounting for real and virtual water. Column (1) shows the prices for one cubic metre of concrete when considering only cement, sand and pebbles; column (2) shows the prices for one cubic metre of concrete when considering cement, sand, pebbles and real water costs (water unit price of R$ 14.04/m3); column (3) shows the prices for one cubic metre of concrete when considering cement, sand, pebbles and virtual water (water unit price of R$ 14.04/m3); and column (4) shows the prices for one cubic metre of concrete when considering cement, sand, pebbles, virtual water and real water.

Resistance	Price (R$)	Price (R$)	Price (R$)	Price (R$)	% Difference	% Difference	% Difference
f_{ck}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
25	234.87	237.54	410.00	412.67	1.14%	74.57%	75.70%
30	249.68	252.35	425.94	428.61	1.07%	70.59%	71.66%
35	265.12	267.79	441.21	443.88	1.01%	66.42%	67.43%
40	275.89	278.56	452.05	454.72	0.97%	63.85%	64.82%
45	289.50	292.17	464.93	467.60	0.92%	60.60%	61.52%

Table 3: Prices and price differences for one cubic metre of concrete when accounting for real and virtual water.
Source: Authors.

Column (5) shows percentage differences between concrete prices while disregarding virtual water but considering real water, which are calculated as the differences between the values shown in columns (1) and (2). The maximum percentage of the price increases is relatively small at less than 1.14%, but according to Crawford and Treloar (2005), although the error is negligible, it cannot be ignored. Column (6) shows the differences between concrete prices while disregarding water and considering only virtual water; these values are calculated as differences between the values shown in columns (1) and (3), which result in a maximum price increase of 74.57%. Column (7) shows the differences between concrete prices while disregarding water and considering both real and virtual water; they are calculated as the differences between the values shown in columns (1) and (4), which result in a maximum price increase of 75.7%. As a result, when considering real and virtual water, the concrete price in the MRB would be in the range of R$ 412.67 to R$ 467.60 for the fck resistances presented in Table 3.

However, the results presented in Table 3 are based on prices of 14.04 R$/m3 for water and 0.56 R$/kg for cement in 2020 (Table 1). This cement price represents U$ 112/ton (Figure 4), and the average historical price of cement in the state of Pará was U$ 198/ton, which could range from U$ 50 to U$ 150 per ton over the next 10 years. For these cement price scenarios, when considering real and virtual water, concrete prices in LCU would be between R$ 322.15 and R$ 347.63 (for a cement price of U$ 50 per ton) or between R$ 468.15 and R$ 541.13 (for a cement price of U$ 150 per ton) when considering the fck values (Table 3).

Therefore, the economic impact for the entire MRB can be evaluated by considering the values of real and virtual water in establishing the concrete price. Figures 5 and 6 indicate that for a per capita consumption of 276 kg/inhabitant and population of 2.5 million inhabitants, the total estimated cement consumption in the MRB is 690,000 tons. The total cement consumption serves to estimate the total amount of sand, pebbles and concrete consumed in the MRB. The values for the total consumption of the MRB were calculated by assuming 2020 prices for cement (0.56 R$/kg), sand (35 R$/m3), pebbles (80 R$/m3) and water (14.04 R$/m3). Fig. 7 shows the calculated values of each component, assuming that all concrete would be produced with only one resistance value. In Fig. 7, the fck values of the concrete are shown on the horizontal axis, and the vertical axis represents the cost shares of components calculated in millions of LCU Reais. The importance of considering the value of virtual water for concrete prices is evident in Fig. 7.

On the other hand, real water does not have a significant influence on total concrete costs. If all concrete consumed in the MRB was produced with fck = 30, for example, the total concrete cost would be 590 million LCU Reais, compared to a cost of one billion when considering real and virtual water. The average percentage of cement was 43.15% for all fck resistances, and the percentage of

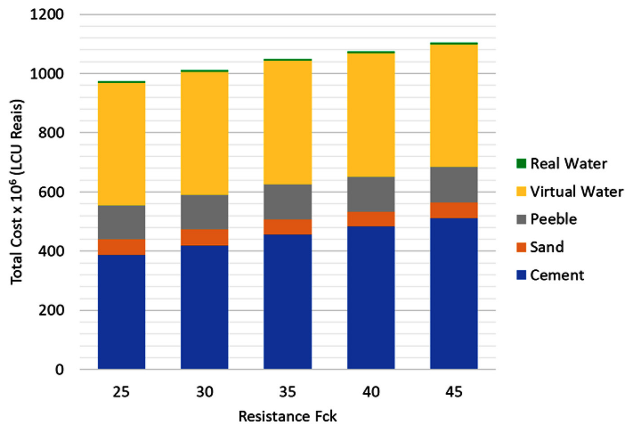

Figure 7: Calculated values of component costs when considering real and virtual water for concrete consumption in the MRB, corresponding to fck values.
Source: Authors.

virtual water was 39.9%. The influence of cement prices on concrete prices has been addressed throughout the present work. Furthermore, the influence of water prices on concrete prices was also required for the simulated

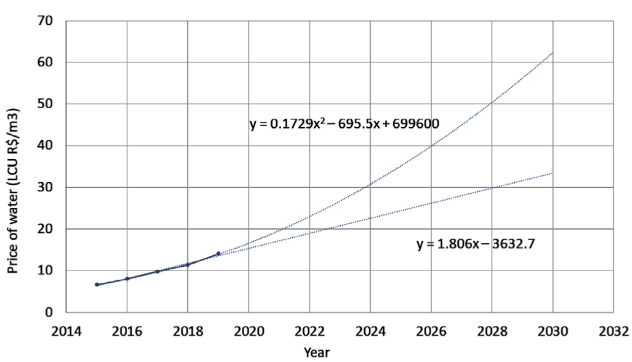

Figure 8: Water prices over the last five years and price projections.
Source: Authors.

projections over the next 10 years. In Fig. 8, water prices for the period of the last 5 years in the MRB are presented, and possible price projections are also shown.

If water price growth is projected as a linear function, at the end of the next ten years, the price of water will be greater than 30 R$/m3. On the other hand, if the growth is a second degree polynomial, the price will be greater than 60 R$/m3. Even if the current price is maintained for cement (0.56 R$/kg), sand (35 R$/m3) and pebbles (80 R$/m3), there is a large impact of water prices on concrete prices. In Table 4, the data of Table 3 are recalculated by using a water price of 30 R$/m3, which show that water prices can have impacts of more than 131% on concrete prices and could reach 161% for the present decade.

5. CONCLUSION

Civil construction is an activity that requires large volumes of water both for needed services and for manufacturing construction materials. A process analysis method was used to account for water in all stages of the concrete production cycle, from the extraction of raw materials up to the construction site. To quantify real and virtual water in concrete, historical time series were analysed and projected for the next 10 years, and spreadsheets were used for the calculations of water inputs and outputs. The costs of real and virtual water were considered for a unit of one cubic metre of concrete since it is not currently valued; only cement, sand and pebbles were assigned unit prices. The results showed that for a water price of 14.04 R$/m3, which was established by the Water and Sanitation Company of the State of Pará (COSANPA), the maximum percentage price increase was less than 1.14% if real water was accounted for, 74.57% if only virtual water was considered, and 75.71% if both real and virtual water were considered.

Unlike the small economic and financial impact that real water has on construction site budgets, the impact of virtual water is relatively high, which would cause an in

Resistance	Price (R$)	Price (R$)	Price (R$)	Price (R$)	% Difference	% Difference	% Difference
f_{ck}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
25	234.87	240.57	609.09	614.79	2.43%	159.33%	161.76%
30	249.68	255.38	626.30	632.00	2.28%	150.84%	153.12%
35	265.12	270.82	641.38	647.08	2.15%	141.92%	144.07%
40	275.89	281.59	652.30	658.00	2.07%	136.43%	138.50%
45	289.50	295.20	664.35	670.05	1.97%	129.48%	131.45%

Table 4: Influence of a water price of 30 R$/m3 on the price of one cubic metre of concrete.
Source: Authors.

crease of 39.9% in the unit price of concrete, which would represent a significant increase in production costs. This increase is amplified when water prices are projected over the next 10 years and may impact more than 131% of final concrete prices. Therefore, the concept of virtual water is potentially of great economic impact for the civil construction sector and requires further research in the future. The present work showed the importance of accounting for virtual water in the final price of concrete and projected values for the coming years.

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REFERENCES

ABCP, 2020. Associação Brasileira de Cimento Portland. **Básico sobre cimento**. Retrieved from. https://abcp.org.br/basico-sobre-cimento/basico/basico-sobre-cimento/?politica=sim. Accessed 01/13/2020.

Allan, J. A., 1998. Virtual Water: A Strategic Resource Global Solutions to Regional Deficits. **Ground Water**, 36 (4), 545–7. https://doi.org/10.1111/j.1745-6584.1998.tb02825.x.

ANA, 2013. **Relatório de Conjuntura dos Recursos Hídricos no Brasil** - 2013. Agência Nacional de Águas. Brasília – DF. 434pp. Retrieved from. https://arquivos.ana.gov.br/institucional/spr/conjuntura/ANA_Conjuntura_Recursos_Hidricos_Brasil/ANA_Conjuntura_Recursos_Hidricos_Brasil_2013_Final.pdf. Accessed 01/10/2020.

Arpke, A., Hutzler, N., 2006. Domestic water use in the United States: a life-cycle approach. **Journal of Industrial Ecology**, 10(1-2), 169-184. https://doi.org/10.1162/108819806775545312.

Barros, F.G.N., Amin, M.M., 2008. Água: um bem econômico de valor para o Brasil e o mundo. **Revista Brasileira de Gestão e Desenvolvimento Regional**, 4(1), 75-108. Retrieved from. http://www.rbgdr.net/012008/artigo4.pdf.

Borges, P.H.R., Lourenço, T.M.F., Foureaux, A.F.S., Pacheco, L.S, 2014. Estudo comparativo da análise de ciclo de vida de concretos geopoliméricos e de concretos à base de cimento Portland composto (CP II). **Ambientente Construído**, 14(2). http://dx.doi.org/10.1590/S1678-86212014000200011.

Cabeza, L.F., Rincón, L., Vilariño V., Pérez, G., Castell, A., 2014. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review. Renewable **Sustainable Energy Reviews**, 29, 394-416. https://doi.org/10.1016/j.rser.2013.08.037.

Carmo, R.L., Ojima, A.L.R.O, Ojima, R, Nascimento, T.T., 2007. Água virtual, escassez e gestão: O Brasil como grande "exportador" de água. **Ambiente e Sociedade**, 10(1), 83-96. https://doi.org/10.1590/S1414-753X2007000200006.

CBIC, 2019. **Consumo, Produção e Valores de Materiais de Construção**. Retrieved from. http://www.cbicdados.com.br/menu/materiais-de-construcao/cimento. Accessed 13/10/2020.

Chen, Z.-M. and Chen, G.Q., 2013. Virtual water accounting for the globalized world economy: national water footprint and international virtual water trade. **Ecological Indicators**, 28, 142–149. https://doi.org/10.1016/j.ecolind.2012.07.024.

Chouchane, H., Krol, M.S. and Hoekstra, A.Y., 2018. Virtual water trade patterns in relation to environmental and socioeconomic factors: a case study for Tunisia. **Science of the Total Environment**, 613–614, 287–297. https://doi.org/10.1016/j.scitotenv.2017.09.032.

Crawford, R.H., Treloar, G.J., 2005. An assessment of the energy and water embodied in commercial building construction, in Australian Life Cycle Assessment Conference, **Australian Life Cycle Assessment Society**, Sydney, pp. 1-10. Retrieved from. http://dro.deakin.edu.au/eserv/DU:30005640/crawford-anassessment-2005.pdf.

da Silva, V., de Oliveira, S., Hoekstra, A., Dantas Neto, J., Campos, J., Braga, C., de Araújo, L. E., Aleixo, D. O., de

Brito, J. I. B., de Souza, M. D., de Holanda, R. M., 2016. **Water footprint and virtual water trade of Brazil**. Water, 8(11), 517. https://doi.org/10.3390/w8110517.

Dalin, C., Konara, M., Hanasakib, N., Rinaldo, A., Rodrigues-Iturbe, I., 2012. Evolution of El-Sadek, A., 2011. Virtual water: an effective mechanism for integrated water resources management. **Agricultural Science**, 2(3), 248-261. doi:10.4236/as.2011.23033.

Elena, G-C., Esther, V., 2010. From water to energy: the virtual water content and water footprint of biofuel consumption in Spain. **Energy Policy** 38, 1345–1352. https://doi.org/10.1016/J.ENPOL.2009.11.015.

Fracalanza, A.P., 2005. Água: de elemento natural à mercadoria. Sociedade e Natureza, 17(33), 21-36. Retrieved from. 9200-Texto do artigo-35247-1-10-20060412.pdf.

Gawel, E., Bernsen, K., 2013. What is wrong with virtual water trading? On the limitations of the virtual water concept. **Environment and Planning** C: Government and Policy, 31, 168 – 181. https://doi.org/10.1068/c11168.

Graham, N.T., Hejazi, M.I., Kim, S.H., Davies, E.G.R., Edmonds, J.A., Miralles-Wilhelm, F., 2020. Future changes in the trading of virtual water. **Nature Communications**, 11, 3632. https://doi.org/10.1038/s41467-020-17400-4.

Gursel, A.P., Masanet, E.r., Horvath, A., Stadel, A., 2014. Life-cycle inventory analysis of concrete production: A critical review. **Cement Concrete Comp**. 51, 38–48. https://doi.org/10.1016/j.cemconcomp.2014.03.005.

Han, M.Y., Chen, G.Q., Meng, J., Wu, X.D., Alsaedi, A., Ahmad, B., 2016. Virtual water accounting for a building construction engineering project with nine sub-projects: a case in E-town, Beijing. **Journal of Cleaner Production**, 112, 4691-4700. http://dx.doi.org/10.1016/j.jclepro.2015.07.048.

Helene, P.R.L., Terzian, P., 1995. **Manual de dosagem e controle do concreto**. São Paulo. Ed. Pini. 349p.

Hoekstra, A., Chapagain, A., 2007. The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities. **Ecological Economics**, 64, (1), 143-151. https://doi.org/10.1016/j.ecolecon.2007.02.023.

Hoekstra A. Y., Chapagain A. K., Aldaya M. M., Mekonnen M. M., 2009, "Water footprint manual, state of the art 2009", **Water Footprint Report**, Water Footprint Network, Enschede, http://www.waterfootprint.org/?page=files/Publications.

IBGE, 2020. Estatísticas. **Contas Nacionais**. Retrieved from. https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9088-produto-interno-bruto-dos-municipios.html?=&t=series-historicas. Accessed 20/11/2020.

Lunardi, J., Figueiró, A., 2012. Problematizando a água virtual em educação ambiental: conceito e forma de cálculo. **Revista Geonorte**, 3(4), 290-300. Retrieved from. https://periodicos.ufam.edu.br/index.php/revista-geonorte/article/view/1945/1820.

Mack-Vergara, Y.L., John, V.M., 2017. Life cycle water inventory in concrete production—A review. Resource Conservation **Recycle**, 122, 227–250. https://doi.org/10.1016/j.resconrec.2017.01.004.

Masud, M.B., Wada Y., Goss G., Faramarzi M., 2019. Global implications of regional grain production through virtual water trade. **Science of the Total Environment**, 659, 807–820. https://doi.org/10.1016/J.SCITOTENV.2018.12.392.

Mccormack, M., Treloar, G. J., Palmowski, L., Crawford, R., 2007. Modelling direct and indirect water requirements of construction. **Building Research & Information**, 35(2), 156-162. https://doi.org/10.1080/09613210601125383.

Meng, J., Chen, G.Q., Shao, L., Li, J.S., Tang, H.S., Hayat, T., Alsaedi, A., Alsaadi, F., 2014. Virtual water accounting for building: case study for E-town, Beijing. **Journal of Cleaner Production**, 68, 7-15. https://doi.org/10.1016/j.jclepro.2013.12.045.

Proença, L.C., Ghisi, E., 2010. Water end-uses in Brazilian office buildings. **Resource Conservation Recycle**, 54, 489–500. https://doi.org/10.1016/j.resconrec.2009.10.005.

Tutikian, B., Helene, P. Dosagem dos Concretos de Cimento Portland. In: ISAIA, G. C L(org.). Concreto: **Ciência e Tecnologia**. 1ª ed. São Paulo: Ibracon, 2011, 1, 415-451.

Vanham, D., Bidoglio, G., 2013. A review on the indicator water footprint for the EU28. **Ecological Indicators**, 26, 61–75. http://dx.doi.org/10.1016/j.ecolind.2012.10.021.

Weidmann, D., Oliveira, A. L., Souza, J., Prudêncio Jr., L. R., Bianchini, M. Avaliação do desempenho de aditivos redutores de água para uso em centrais de concreto: Estudo de caso. **Anais. In: 49º Congresso Brasileiro do Concreto**. 2007. Bento Gonçalves – RS. 16p.

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LPGLB: conceptualization, data curation, investigation.
AAAMD: conceptualization, funding acquisition, methodology, project administration, software, visualization, writing – review & editing.
CJCB: conceptualization, formal analysis, funding acquisition, methodology, project administration, validation, visualization, writing - original draft, writing - review & editing.
ACMB: formal analysis, methodology, software, supervision, validation, visualization, writing - original draft, writing - review & editing.
MSP: conceptualization, funding acquisition, methodology, supervision.
MFM: data curation, investigation.
RGP: data curation, investigation.

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