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Assessment of carbon pollution in Kabul river and its solutions based on the material flow analysis model, ESRISS

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ABSTRACT

Kabul river is the main river in Kabul city and eastern Afghanistan which passes through 200 kilometers of the heart of Kabul. For the river to serve its ecological purposes, like water supply and environmental quality control, water flow should be optimized both in terms of quantity and quality. However, the water in its inundation season, spring, is very high in pollution and the river bed is waterless and full of solid wastes throughout the rest of the year. The goal of this research was to present a quantitative assessment of carbon as a water quality parameter in Kabul river in the geography of Afghanistan, to detect probable sources of this pollutant and to suggest feasible pollution management approaches. The study was based on the Material Flow Analysis (MFA) model, developed by the Egyptian-Swiss Research on Innovation in Sustainable Sanitation (ESRISS) Project. The effect of hydropower dams, in the concentration of carbon in the river, as a water quality parameter, was evaluated. A segment of the river between the Naghlo hydropower dam and the Darunta dam was chosen for carbon content analysis. As a result of this analysis, we can provide data for carbon quantity in the specified segment of the river. Moreover, we will be able to apply this methodology for providing water quality analysis for almost any segment of the river and suggest relevant feasible solutions for water pollution problems.

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1. Introduction

Kabul river is a transcountry river that originates from the mountains of Paghman in Kabul and terminates in Atak of Pakistan. Water quality is deteriorating in this culturally and environmentally crucial river due to excessive industrial and agricultural effluent discharges and due to many other factors. Figure 1 shows the direct discharge of waste effluents to the river from nearby vendors, which is one of the major causes of pollution and unpleasant odor in this area. In this paper, we are going to review the possibility of applying the MFA model on Kabul River for purposes like water quality management. "MFA is a tool to quantify the flows and stocks of materials in arbitrarily complex systems." [1]. We will choose a portion of the river, located inside Afghanistan, and using the MFA tool, we will quantify a certain type of pollutant, namely, carbon in the relative water body. The review is going to be mainly based on the material flow analysis model, which was initially used by ESRISS (Egyptian-Swiss Research on Innovation in Sustainable Sanitation) in the Nile river delta. Previously, numerous researches have been conducted on the Kabul River, aimed to quantify and control its pollution. Most of these researches are focused on the more downstream portion of the river that flows in the land of Pakistan. IUCN's report on Kabul river presents a quantitative evaluation of pollutants in the river segments outside Kabul's borders. With the model obtained from this study, we can provide site-specific water quality data for any segment of the river.

Overall, parts of Kabul River flowing in central urban areas of Kabul, are more polluted than at the town's outskirts. Figure 2 is an indicator of the accumulation of solid wastes in the Kabul River in Foroshgah, a central business area of the city. Various dangerous contaminants pollute the water that, besides other harms, suffocate the aquatic creatures living in the water body. Whether it is high

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concentrations of pollutants in central city areas or relatively lower pollution levels in peripheral areas, the main problem that hinders the attempt of enhancing water quality is a gap of site-specific and recent data. Thus, the MFA tool is utilized to generate specific water quality data. This paper specifically analyzes the amount of carbon in the River, which is a dangerous pollutant not only for the river water quality but also to the atmosphere. "An international research project has found that the amount of carbon being released from rivers into the atmosphere is larger than previously estimated in the world's most extensive peat regions in Western Siberia" [2].

Figure 1. Direct discharge of waste water to the river in a central part of the city (by courtesy of Ghafoor Haqdost).

Figure 2. Solid waste accumulation in the river body (by courtesy of Ghafoor Haqdost).

2. Proposed solution mechanism

The mechanism selected for the solution of the problem stated above (high-level water pollution and lack of site-specific data in Kabul river) is using the MFA model. MFA is generally based on mass balance and mass conservation principles. In simple terms, it takes into account what enters a system, what leaves it, and what happens in between. Pollutant concentrations are presented as a function of time at the end, which helps us make estimations and predictions.

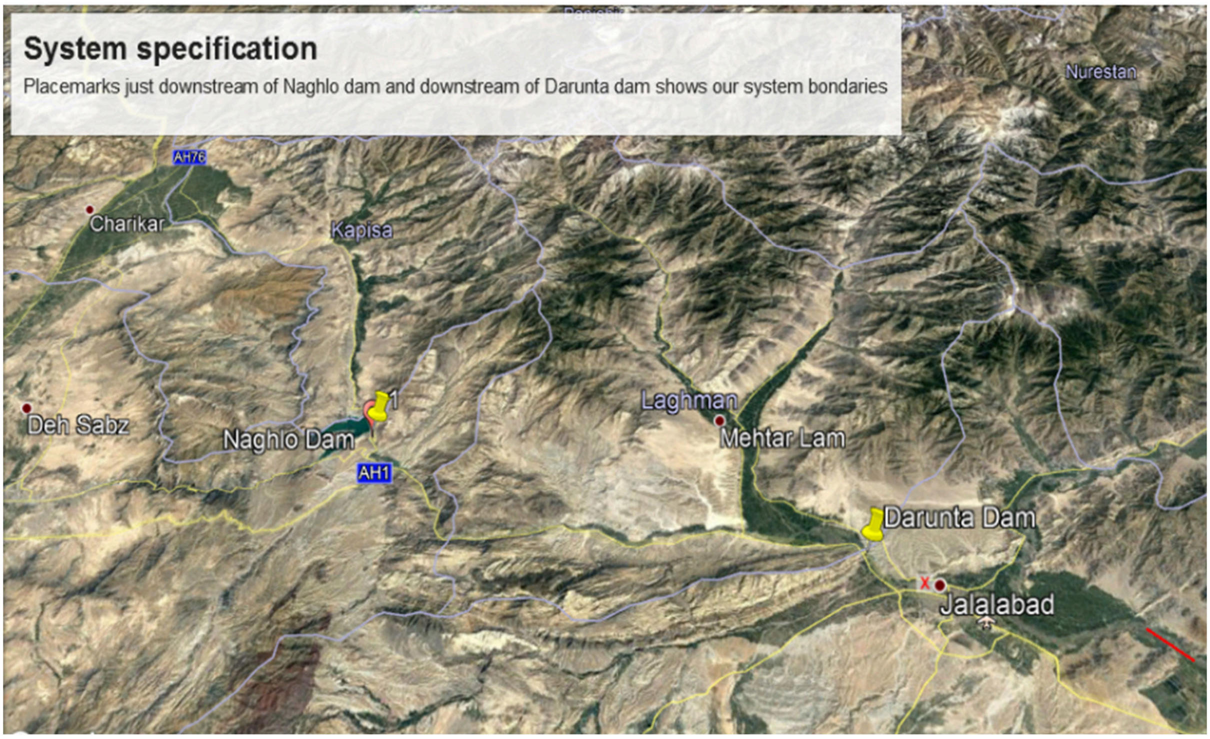

Figure 3. System boundaries.

3. Methodology

Using Google Earth, we specify a section of Kabul river flowing inside Kabul city and mark the start and end of the section by their geographical coordinates, which works as our system boundaries, defining the enclosed area as our "system." Then we specify the "substance" for flow analysis. According to Montangero [3], a substance is any chemical element or compound or water quality parameter that we want to quantify. Then we mark all considerable sources of this substance that flows into this section of the river, which according to the MFA model, is called the "processes." The next step is to provide a fair estimation of the amount of the substance discharged to the river from each of the detected sources that come across the chosen path.

4. Results and discussion

As a result of applying the above methodology, we select the section of the river flowing between the downstream of Naghlu dam and the downstream of Darunta dam located at 34º 38' 25'' N 69º 43' 02'' E and 34º 29' 04'' N 70º 21' 48'' E, respectively. It covers a distance of 77km along the river (Figure 3).

This portion of the river was selected based on the substance to be quantified which is carbon. Dams' cleanout processes are a major source of carbon release in rivers. According to part of the NHRP [4] report which discusses the potential environmental hazards of the dam, lubricants and oil together with some sediments form the products of the dam's cleanout process that discharge to the river downstream from the dam reservoir [5]. Lubricants are used for maintenance, increased efficiency, and protection against oxidation in hydropower machinery. These lubricants, in terms of MFA, are the "process" for this model and are of the type of mineral oil which in turn is 90% composed of petroleum. It is evident from chemistry that petroleum is a mixture of different types of hydrocarbons, most commonly alkanes, C_nH_{2n+1}, which consist of approximately 30% carbon. This carbon from the cleanout process of the dams, namely, Naghlo and Darunta and Sarobi (located between the 2 aforementioned dams) together with any considerable carbon-containing effluent or river tributary is added.

It is mentioned in the Electrical Engineer reference book that Llubricating oil consumption may be taken to be 1.5% of fuel oil consumption at full load [6]. According to Laughton, the cost of fuel consumption can be estimated as one-eighth of the cost of produced electricity expressed in terms of currency/kilocalorie. DABS [5]reported the overall capacity of the four turbines of Naghlo dam as 94 MW (23.5 each) and the cost of the project is estimated at 77.5 million USD, while one kilowatt-hour is equivalent to 860.421-kilocalorie. The calculations are as shown below:

For Naghlo dam (Figure 4):

Considering 3 working turbines at a time:

70.5 MW = 70500 KW

Considering 1-hour duration:

75000 kW*1hr = 75000 kW-hr

75000 kW-hr = 64531575 kilocalorie

(77.5 million USD)/(70.5 MW)=1.099 million USD/megawatt-hour = 1099 USD/kWh = 1.27 USD/kilocalorie

Hourly fuel consumption cost = (1/8)*1.27 USD=0.158USD

The above cost corresponds to 0.039 litres of fuel consumption in an hour, as 1 litre of the oil costs 4 USD (DABS).

Hourly lubricant consumption = (1.5/100)*0.039 L = 0.000585 L = 0.585 cm^3

Petrolium volume = 0.9*0.585 cm^3 = 0.5265 cm^3

Carbon share = 0.3*(0.5265 cm^3) = 0.15cm^3

Density of carbon = 2 gr/cm^3

Hourly carbon mass introduced to the river = (2 gr/cm^3)*(0.15 cm^3) = 0.3 g.

There is another hydropower dam built on the Kabul river on this path, between the two system boundaries, namely, the Sarobi dam. This dam with geographical coordinates 34º, 35' 11'' N and 69º, 49' 32'' E has an overall capacity of 22 MW and a total production cost of 31 million USD [7]. We have the following:

22 MW=22000 kW

Considering 1-hour duration:

22000 kW*1hr = 22000 kW-hr

(31 million USD)/(22 MW) = 1.409 million USD/MW = 1.409 million USD/MW-hr = 1409.09 USD/kW-hr

=1.63 USD/kilocalorie

Hourly cost of fuel consumption = (1/8)*(1.63) USD = 0.2 USD

which corresponds to 0.05 L fuel.

Hourly consumption of lubricant = (1.5/100)*0.05 L = 0.00076 L=0.76 cm^3

Volume of petroleum = 0.9*0.76 cm^3 = 0.684 cm^3

Share of carbon = 0.3*0.684 cm^3 = 0.2 cm^3

Hourly mass of Carbon introduced to river = (2 g/cm^3)*0.2 cm^3 = 0.4 g

Figure 4. Naghlu hydropower dam [8].

Simillarly for Darunta dam (Figure 5), having the production capacity of 8 MW and total project cost of 11 million USD [9], we have the following:

8 MW = 8000 kW

Considering a 1-hour duration;

8000 kW*1hr = 8000 kW-hr

(11 million USD)/8 MW = (1.375 million USD/MW)= 1375 USD/kW-hr = 1.59 USD/kilocalorie

Hourly cost of fuel consumption = (1/8)*1.59 USD=0.2 USD which corresponds to 0.025 L fuel.

Hourly lubricant consumption = (1.5/100)*0.025 L = 0.000375 L=0.375 cm^3

Petrolium volume = 0.9*0.375 cm^3 = 0.3375 cm^3

Carbon share=0.3*0.3375 cm^3 = 0.1 cm^3

Hourly carbon mass introduced to the river = (2 g/cm^3)*0.1 cm^3 = 0.2 g

We assume that no tributary with critical carbon content enters the river at this interval.

Figure 5. Darunta hydropower dam.

In this study, we had the option of choosing a section of the river flowing across Kabul's industrial hub located in the 9th district, in which there are many factories including the $25 million Coca-cola bottling and Omaid Bahar food processing factories. Nevertheless, due to an excessive number of effluent discharges from factories and agricultural lands, and the lack of specific flow data, it was not selected. Rather we chose a more isolated and out of the city's center system location with lesser effluents and entering pollutant varieties to be able to provide a clearer application of the MFA. Another reason for the selection of this location was to depict the effect of hydropower dams on the concentration of organic carbon in the river.

If we assume the carbon content of the water upstream from our first system boundary (Naghlo dam) to be *X*, and we assume that no tributary with critical carbon content enters the river at this interval, then the equation for the amount of carbon considering the share of the three dams is as follows:

$Mc = X+0.3t+0.4t+0.2t$

$M_c = X+0.9t$-----------I

,where *t* is time in hours.

If we integrate the two sides of the equation, treating *X* as a constant, we have ;

$dM/dt = Xt+0.45t^2$-----------II

Equation (I) shows the amount of carbon after time t in the system, while equation (II) indicates the carbon mass rate of change.

5. Conclusion

In this study, we evaluated the effect of hydropower plants in the carbon content of the Kabul river within a specific system boundary. Model equations were developed for carbon content in the system as a function of time and the rate of change of this variable. Although in the form of suspension, the carbon released into Kabul river from hydropower plants can be critical over time, which in seasonal droughts, is more dangerous due to low assimilation capacity.

The main goal of this study, which was to show the application of MFA in Kabul river for quantifying a water quality parameter, is achieved by developing equations that show the amount of carbon released by the dams' cleanout process. For a solution to this aspect of the problem of water pollution in the Kabul river, it is suggested that environmentally friendly lubricants be used to limit carbon discharge into the river.

Another solution is to increase the assimilative capacity of the river, which helps decrease the effect of this pollutant in the river body. The model obtained in this study can be easily modified to provide different data, different pollutants, in different river segments.

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