Development of a basin management program to improve water quality in rivers based on an environmental water quality predictive model

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ABSTRACT

This research has the aim of establishing the amount of land that the Conservation Area National System (SINAC) needs to buy and specifying its use inside the Golfo Dulce Forest Reserve in order to maintain the good quality of the rivers. The study was done inside Rincon sub-basin in the Osa Peninsula, a land dedicated to primary and secondary forest (Melina tree plantations), mangrove forest, urbanism, chaparral, pasture for grazing livestock and crop cultivation, mainly rice and African palm; uses that may change in time affecting the actual water quality (WQ) in rivers and the bay. Changes in land uses modify the WQ and it can be predicted using WQ models based on environmental variables through the evaluation of different scenarios. It was found through modeling that pasture or chaparral land use has no negative impact on WQ; all the contrary happens with increments in crop cultivation or human population. At the present, the coastal area, adjacent to the reserve, has low agricultural activity but that could increase over time, affecting the WQ. Therefore, SINAC should continue with its acquisition land activity to counteract the negative environmental effect of agricultural activity to preserve the actual good quality of the rivers.

Key words | basin environmental management, integrated water resources management, water quality restoration

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INTRODUCTION

SINAC is the government agency responsible for the Golfo Dulce Forest Reserve (RFGD) and park protection. This agency focuses on the regulation of the hydrological regime and the conservation of the environment as well as the watersheds. In addition, SINAC has purchased land from private landowners inside the RFGD since the 1990s. Land purchasing has been done without any plan of action for land acquisition or any criterion for its future use and environmental impact (Robleto-Villalobos 2018).

The Osa Peninsula requires environmental protection since one-third of the existing tree species as well as 30–50% of all known animal species in Costa Rica are found there (Figure 1). The Corcovado Park and the RFGD are protected areas located on that peninsula. The RFGD includes cloud forests, wooded areas, grazing pastures and a diversity of microclimates (Figure 1). The coastal zone abounds in mangrove ecosystems that represent natural capital for the communities (Robleto-Villalobos 2018). The RFGD is a strip that has the Corcovado National Park on one side and a coastal zone on the other (Figure 1). Corcovado Park is a wildlife conservation area owned entirely by the government so that this land will remain as forest; meanwhile, the RFGD land has private ownership as well as government properties; therefore, the government has limited control on its land use. The coastal area is private land, where the government has no control on its use and it is mainly dedicated to rice and African palm cultivation at this moment, activities that not only affect the river

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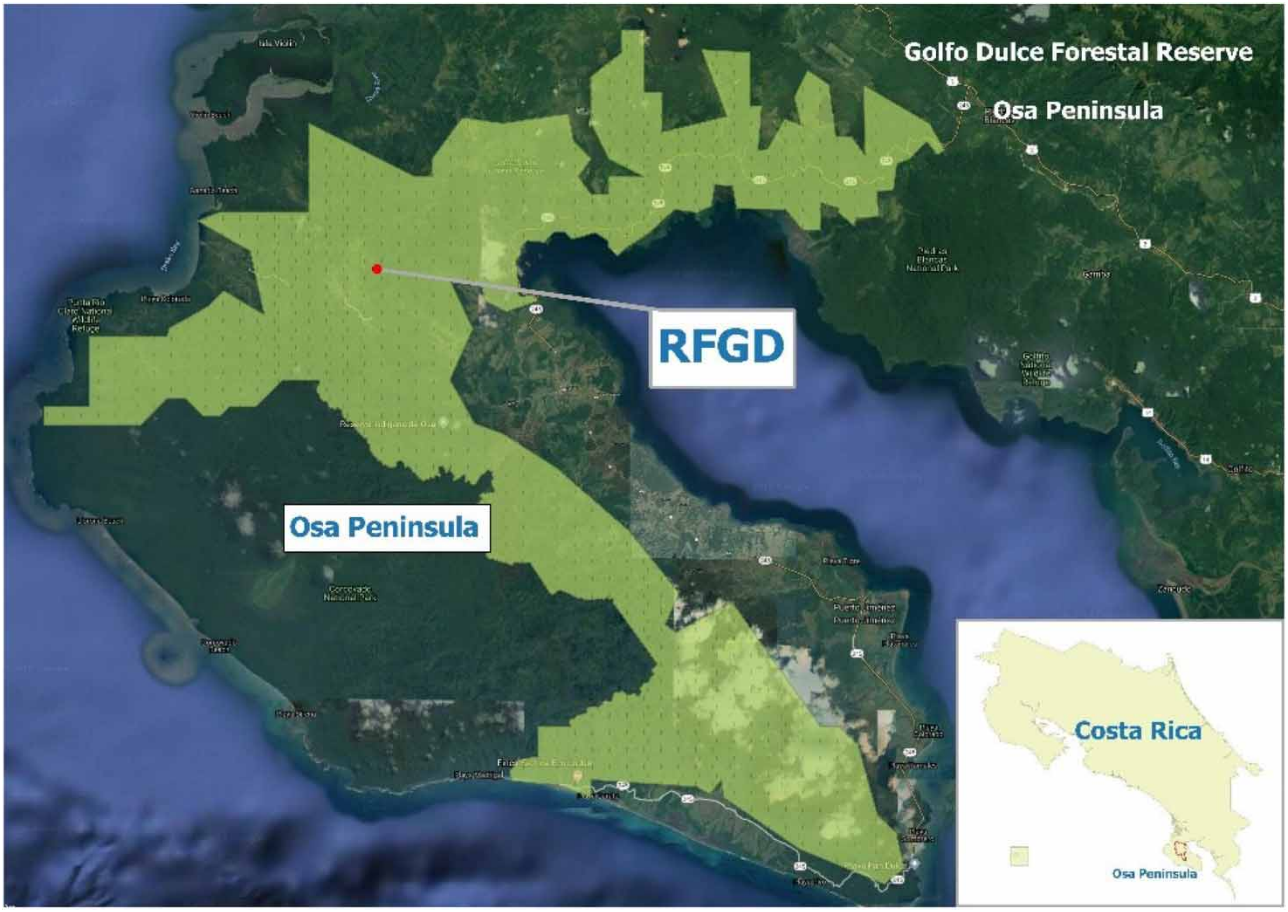

Figure 1 | Location of the RFDG in the Osa Península. *Source:* amended from Calvo-Brenes *et al.* (2016).

water quality (WQ) but also the multiple mangrove areas as well as the Golfo Dulce bay waters. In the last few years agricultural activities have increased (Robleto-Villalobos 2018).

Since rivers, mangrove areas and the bay have a strong relationship with economic and social activities as well as public health in this area, it is in that sense that good WQ should be protected and can be used as a criterion for establishing land-buying procedures in the RFGD.

WQ is measured by different quality indicators that can be grouped in one single value or index (WQI) (FAO 2001; Abbasi 2002). However, a good design of the index leads to a value that is representative of the quality of the water and its tendency (León Vizcaíno 1992). In addition, a WQI represents a tool for easy understanding and interpretation for decision makers (León Vizcaíno 1992; Cude 2001; Swarnee & Tyagi 2007). Moreover, WQ can also be classified in categories or classes, depending on different levels of contamination (Calvo-Brenes 2018). In Costa Rica, the legislation considers five different classes, each one representing different levels of contamination and each class may have several associated uses (MINAE 2007).

The hydrographic basins, as well as the sub-basins and micro-basins, are geographical units that are characterized by collecting the rainwater and channelling it towards a main river (FAO *et al.* 2013b). It is in this space where the strongest interactions occur between the use and management of natural resources (anthropic action) and the reaction of the environment (FAO *et al.* 2013a). Changes in the use of natural resources upstream have a positive or negative impact on quantity and quality downstream (Dourojeanni *et al.* 2002; Kang *et al.* 2010; Wyer *et al.* 2010).

The quality and volume of river waters are influenced by complex hydrological phenomena that depend on the type and age of trees in the forest, season of the year, soil texture, structure or presence of organic matter in the soil, as well as the geomorphology of the surroundings (Astorga 2008; Yu *et al.* 2015). Deforestation, overgrazing, as well as excess in agricultural activities and type of crops, usually lead to increments in erosion and runoff, conditions that finally affect water quality (FAO 2001). The main parameters that intervene in the conversion of rainfall to runoff are: basin area; total height of precipitation; general characteristics of the basin, like its shape, slope and vegetation; distribution of rainfall over time; and spatial distribution of rainfall (Aparicio 2009; Kang *et al.* 2010).

Changes in WQ caused by changes in land uses can be predicted using WQ models based on basin environmental variables through the evaluation of different scenarios. Predictive models (Equation (1)) developed and validated by Calvo-Brenes (2013) were used to evaluate those changes, mainly in the coastal zone where government has no control and agricultural activity tends to increase:

$$WQI = \beta_1 X_1 + \ldots + \beta_n X_n + \beta_o \quad (1)$$

where

WQI: water quality index
β_i: slope of every independent variable
X_i: environmental variables
β_o: intercept.

The model has two components as shown in Equation (1): a WQI as the response variable and different predictor (environment) variables. A statistical model must be drawn up with the fewest possible predictor variables for the model to be parsimonious (Montgomery *et al.* 2012) and, in turn, must be sufficiently representative of the desired reality modeling (Blenkner 2008). Therefore, models help us predict future changes or different options for ecosystem management. Despite their great value, they are not exact; even though this represents savings in money and time (Blenkner 2008).

Calvo-Brenes's models were developed for Costa Rica considering its environment and the local government regulations. For model development, 33 different environmental variables that influence water quality were initially used, according to information given by Aparicio (2009), Calvo-Brenes & Mora-Molina (2007), Guerrero (2011) and Cross (2007):

- flow rate;
- precipitation (mm): total monthly, accumulated annual, monthly average and accumulated for 2 days during and before sampling;
- density: housing (number of houses per square kilometer) and population (number of inhabitants per square kilometer);
- presence of sewage treatment systems (%): sewer, septic tank, latrine, other system, has no system and has some (which is the sum of septic tank, latrine and other);
- slope along the river (%): average slope, maximum slope and average slope from point 1 to 3;
- transversal slope (%): average and maximum;
- current order (u);
- density: of currents (D_s, units/Ha) and drainage (D_d, meters/Ha);
- riparian coverage (meters);
- soil texture: sand content (%), silt (%), clay (%) and water infiltration rate;
- land coverage (%): urban use, use in seasonal or permanent crops, in pastures, in forests or as charral-tacotal;
- year season: winter or summer.

Thirty different sampling points were evaluated during a 1-year period and each month. The Multivariate Linear Regression model was generated using the SPSS software and using WQI data as the response variable and the different environmental variables as predictor variables. In addition, the 'Stepwise' algorithm (Dzialowski *et al.* 2009) was selected as part of the process for the reduction of variables, using an input alpha of 0.05 and an output alpha of 0.15. Variation Inflation Factor (VIF) and Pearson Bivariate Correlation Coefficients (PBCC) data were evaluated for potential collinearities. The criterion used was VIF values > 10 and PBCC values close to 1, as indicative of possible collinearities (Montgomery *et al.* 2012). Tables 1 and 2 show the environmental variables selected for the two models after the application of the variable reduction stage.

Model validation was done in another 1-year period with 12 different sampling points, following Montgomery *et al.* (2012) validation recommendations (Calvo-Brenes 2013). The variability between the observed and predicted

Table 1 | Predictive model 1 and its environmental variables

Predictor	β	Predictor	β
Intercept	132.316	Sand	−0.974
Riparian use	1.149	Stream order	−9.659
Average transversal slope	−1.820	Current density	2,235.553
Drainage density	−0.797	Human population density	−0.002567
Pasture	0.578	Urban use	−0.230
Silt	−2.493	River flow rate	−0.000474

Source: Calvo-Brenes (2013).

Table 2 | Predictive model 2 and its environmental variables

Predictor	β	Predictor	β
Intercept	104.440	Average slope	0.312
Human population density	−0.0036	Chaparral	1.240
Soil texture class	−3.564	Maximum slope	0.241
Drainage density	−0.764	Silt	0.619
Urban use	−0.319	Perennial crops	−0.187
Maximum transversal slope	−0.400	Sand	−0.261

Source: Calvo-Brenes (2013); where: β: coefficient or slope, Predictor: each environmental variable.

values during the validation process allowed the determination of the uncertainty. The average prediction error was calculated to determine the sensitivity of the model using Equation (2):

$$APE = \sqrt[2]{\frac{\sum_1^n (y_i - \hat{y}_i)^2}{n}} \tag{2}$$

where

APE: average prediction error
n: number of samples
y_i: WQI observed
$\hat{y}_i$: WQI predicted.

The prediction model developed using environmental variables has an adjusted determination coefficient (adjusted R^2) of 83.9%, which makes it reliable; moreover, it is parsimonious and robust. The observed and the predicted WQI values show correlation coefficients with high confidence levels that demonstrate the reliability of the model. Likewise, the sensitivity of the model, measured through the average prediction error, is 7.2 percentage points during validation analysis (more details in Calvo-Brenes 2013).

The project objective was to use two water predictive models as a tool for the elaboration of an environment protection program based on RFGD land acquisition procedures to protect or improve the WQ of rivers. It was accomplished through the evaluation of different scenarios, considering those environmental variables that may change in time and have a direct impact on water quality (Montgomery *et al.* 2012; Calvo-Brenes 2013).

MATERIALS AND METHODS

Site description

The Osa Peninsula consists of Tropical Wet, Premontane Wet, and Tropical Moist forest types. Mean annual precipitation is 5,500 mm, distributed between a dry season (December–April) and a wet season (May–November). Mean annual temperature is 27 °C. Elevations on the Osa Peninsula range between 200 and 760 meters above sea level (m.a.s.l.). The average slope is 40%, with significant areas close to 90% and 100% (Sanchez-Azofeifa *et al.* 2002). Land use is dedicated to primary and secondary forest (melina tree plantations), mangrove forest, urbanism, chaparral, pasture for grazing livestock and crop cultivation, mainly rice and African palm.

The Rincon sub-basin has three distinguished zones, each having very low human population density (Figure 1). A small area of the Corcovado park is in the upper zone of the sub-basin; therefore, this area is forest with wildlife that affects the quality of the rivers, especially in the wet season. The RFGD is in the middle zone, where the land is mainly dedicated to forest, melina plantations and grazing livestock. The lower side is close to the Golfo Dulce bay where there is mangrove forest. Rice cultivation and African palm plantations are common activities in this area as well. The coastal area accounts for 20% of the total area of the total Rincon sub-basin, as well as the park sharing a similar area; meanwhile, the RFGD represents around 60%.

Sampling points

The study was carried out in the Rincon sub-basin (Figure 2). Basins, sub-basins or micro-basins must be selected for research purposes since they are considered basic units for environmental planning.

First, the actual WQI (real value) of the river must be measured and its average value calculated since the predicted WQI value should remain within the model error (Calvo-Brenes 2013).

Water samples were collected at the lower part of the sub-basin every 2 months from May 2014 until January 2015. Any source of contamination that may occur upstream is reflected downstream.

Five different sampling points were selected since the main river (Rincon) is affected by tributary rivers (Riyito and Aguabuena); therefore, WQ variations should be monitored. Aguabuena Creek was monitored (G-5) and its waters are discharged into the Riyito River; consequently, it is convenient to monitor the Riyito River, before (G-3) and after (G-1) receiving the Aguabuena waters. On the other side, Rincon River receives both the Riyito and Aguabuena waters. For this reason, Rincon is monitored before (G-2) and after (G-4) receiving those waters (Figure 2). This procedure helps the tracking of any abrupt changes in WQI values in relation to the rest of the sampling points.

WQ indicator analysis

WQ indicators required for the index were nitrates, biochemical oxygen demand, ammonia nitrogen, alkalinity, phosphate phosphorus, percentage of oxygen saturation, turbidity and fecal coliforms (Calvo-Brenes 2013). The method used for water sampling and indicator analysis was according to

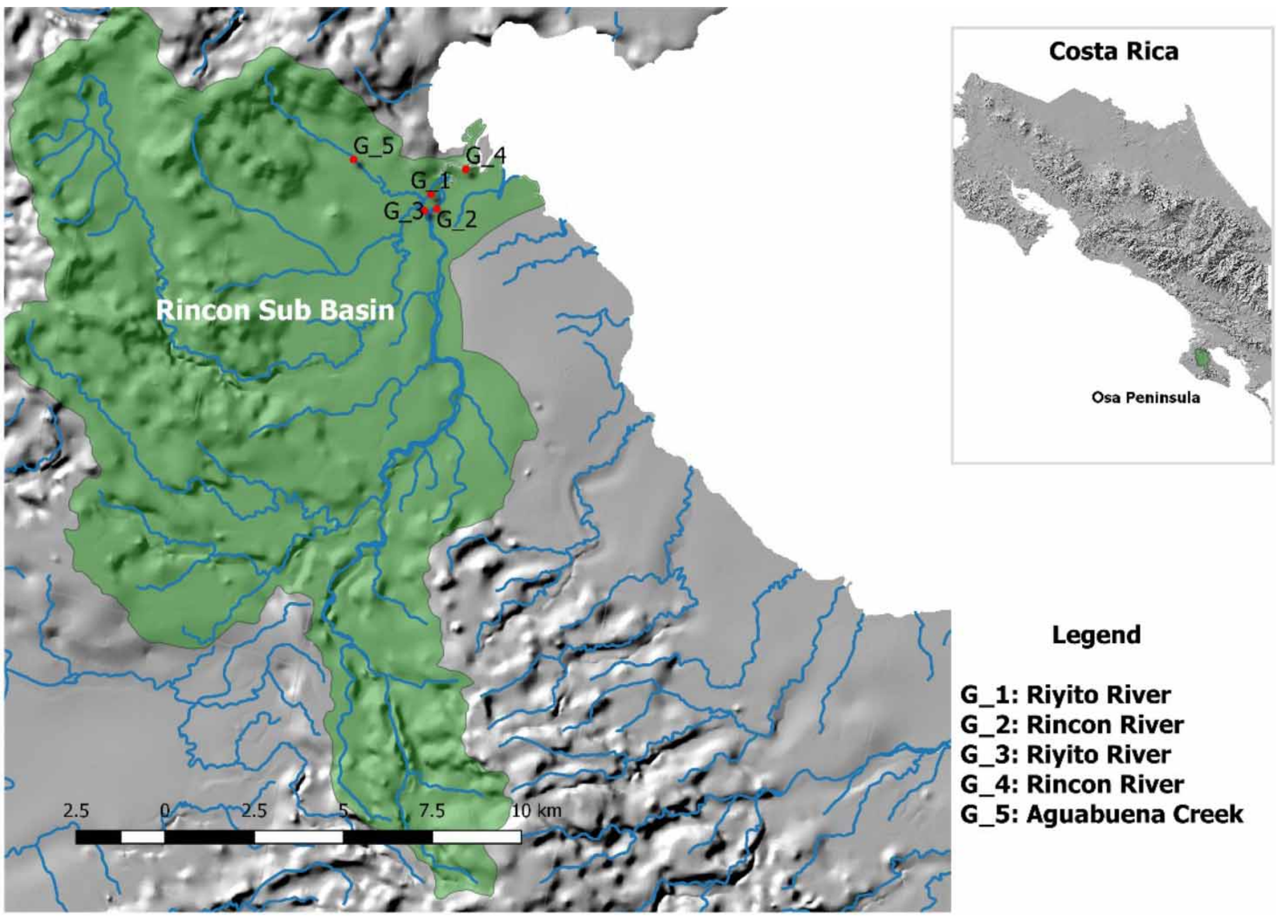

Figure 2 | Sampling points in the Rincon sub-basin at Osa Peninsula. *Source:* amended from Calvo-Brenes *et al.* (2016).

Figure 3 | Water quality classification diagram based on WQI ranges and colors. *Source:* Calvo-Brenes (2013).

procedures established in *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.* 2012).

Subindex (SI) calculation

Each WQ indicator must be transformed from a water concentration measurement to a new 0–100% scale (SI) and this previous stage is required for the WQI calculation. Figure 3 shows the WQ Costa Rican classification diagram based on different ranges, colors and classes. The WQI-SI scale is divided into five different WQI-SI ranges or Classes: Class 1 corresponds to no polluted waters in a range from 90% to 100%, Class 2 means incipient contamination (80–90%), Class 3 corresponds to moderate contamination (50–80%), Class 4 is for severe contamination (20–50%) and Class 5 is for very severely contaminated waters (0–20%).

The different SI calculations needed for Equation (3) were carried out using transformation formulas developed by Calvo-Brenes, using the WQ national legislation (MINAE 2007) as well as a WQ classification diagram (Figure 3) based on colors and ranges required for this calculation (Calvo-Brenes 2013).

WQI in rivers

The index was calculated using the SI values of each indicator and the WQI aggregation Equation (3), proposed by Dojlido *et al.* (1994); (Calvo-Brenes 2013) and this value represents the real WQI value:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}} \tag{3}$$

where

WQI: water quality index
SIi: the subindex of each WQ indicator
n: number of SI.

Predicted WQI

The predicted WQI were obtained using two predictive models selected for that purpose and developed by Calvo-Brenes (2013). Predicted WQI values are based only on environmental variables. More details about this technique are found in Calvo-Brenes (2013).

Those models were previously developed using 1-year-period data obtained through the monitoring of 30 different sampling points each month. Model validation was done through another 1-year-period of testing, according to the recommendations of Montgomery *et al.* (2012). Results showed a 4.3% standard deviation and a 7.2% error deviation between WQI values obtained using the predictive model and the WQI values (real values) measured in the river during the validation stage in the second year (Calvo-Brenes 2013). The different statistical tools used to reduce the number of environmental variables helps in the selection of the most influential ones for the model. The first variable introduced in the model was human population density and the coefficient of determination became 77.4%, meaning that this is the most important variable by far and the other variables are much less important for the model's behavior. This might be a reason why the model's accuracy has a low error deviation (Calvo-Brenes 2013).

Environmental variables

Environmental variable data were gathered to predict the WQI (Tables 1 and 2). Model 1 requires the measurement of human population density, slope (average transversal), soil texture (silt and sand content), drainage and current density, land use (riparian, pasture and urban), stream order and river flow rate. Model 2 is based on human population density, soil texture (sand, silt and texture classification), drainage density, land use (urban, chaparral and perennial crops) and slope (maximum transversal, maximum and average) (Calvo-Brenes 2013).

The riparian zone was analyzed using satellite imagery generated in the Google Earth program. It was measured upstream of the sampling point on the river. Since this varies along the river, the stream was divided into 10 segments, following the riverbed. The transverse length of the river was determined in each segment that has forest cover and is limited by areas lacking forest vegetation, and the average value was used as a variable (Calvo-Brenes 2013).

The soil texture was analyzed to determine its composition in relation to its sand, silt and clay percentages based on the method of Bouyoucos (1962).

The river flow order variable was calculated by determining the number of tributary streams that finally make their individual contribution to the mainstream (Aparicio 2009). Since the flow order variable depends on the resolution of the cartographic maps, those tributary streams that are displayed on a scale map of 1:50,000 account for its calculation.

Other variables analyzed were the current density Ds (Equation (4)) and the drainage density Dd (Equation (5)). The first is defined as the number of perennial or intermittent currents per unit area, while the second is the length of currents per unit area (Aparicio 2009). Both the current numbers and their length were determined on a map, with a scale of 1:50,000. The area of the sub-basin was obtained from the database that generated the Quantum GIS (QGis) program, during the analysis of the multispectral images. Both variables were calculated as follows:

$$D_s = \frac{N_s}{A} \quad (4)$$

$$D_d = \frac{L_s}{A} \quad (5)$$

where

N_s: number of perennial or intermittent currents
L_s: length of currents
A: micro-basin area.

There are several methods for the slope calculation and the average slopes were calculated using the method described by Aparicio (2009). The slopes were calculated for each sampling point, following the direction of the upstream riverbed. Transverse measurements at sampling points were carried out, for both the left and the right side as well as the transverse mean value (left and right side calculated together).

Precipitation data were obtained from the Instituto Meteorológico de Costa Rica.

Land use

Land use in Rincon sub-basin was done using Landsat 8 satellite images obtained from the United States Geological Survey (USGS 2014) with software Quantum GIS version 2.18.4. More detailed data for land use were possible from a land-use survey carried out in research done at Stanford University on the Osa area (Broadbent 2015).

Analyzing model scenarios

The evaluation of possible future changes in WQI can be done using the two models and considering different scenarios in terms of population density and different coverages–land uses, variables that may change in time and have a direct impact on WQ. Other variables that are part of the model, like soil texture, are used in the models for WQI calculations but they are not expected to change in the long term.

Modelling was done using an Excel spreadsheet having one cell for calculating the predictive WQI and in others, each environmental variable. First, the actual values measured at the moment of the research were introduced for each environmental variable to calculate the predicted WQI. Later, the variables that might change in the future were used considering different future conditions.

RESULTS AND DISCUSSION

WQI at sampling points

Five sampling trips from May 2014 to January 2015 were organized to evaluate the WQI at five different sampling points and the results are shown in Table 3. WQI in each cell are uniform in magnitude around Class 1 (no contamination) with some exceptions. Data analysis of G-3 in trip 1 and G-4 in trip 2 and 3 showed moderate contamination caused by high levels of fecal coliforms. Human population density is practically null; therefore, the only

Table 3 | WQI values for each sampling trip

Sampling point	Sampling trip 1	2	3	4	5	Average
G-1	92.0	92.7	89.5	93.6	95.1	92.6
G-2	94.3	95.9	93.0	94.8	95.8	94.8
G-3	61.7	94.1	91.1	27.2	94.8	73.8
G-4	91.4	60.9	61.5	92.1	48.2	70.8
G-5	94.9	95.1	94.5	92.9	96.7	94.8
					Average	85.4

Note:
1. CONTAMINATION LEVELS:
None for Class 1; Low for Class 2; Moderate for Class 3; Severe for Class 4; Very severe for Class 5

Source: amended from Calvo-Brenes *et al.* (2016).

source of this contamination must be wildlife and some grazing livestock upstream. G-3 in trip 4 corresponds to severe contamination (Class 4) caused by an oxygen saturation of 140%; meanwhile, G-4 in trip 5 was due to a high value in nitrate concentration.

Heavy rains in the Osa Peninsula are normal and usually happen in a small area and over short periods of time, while in other nearby areas it might not be raining. Intense rains over clay–silt soils, typical of the peninsula, cause runoff that carries contaminants from the surface to the river. This typical behavior might be the one responsible for different contamination levels among some sampling points; unfortunately, there is no precipitation data to probe this hypothesis.

Environmental variables

Land use

Figure 1 shows that the RFGD is located inside and outside the Osa Peninsula and Figure 4 reveals that the RFGD crosses the Rincon sub-basin (green line in Figure 4). Therefore, Rincon can be divided into three main areas: the RFGD in the middle; the Corcovado Park, a forestall zone in the upper side; and a coastal area located in the lower sub-basin zone, as mentioned before.

According to Figures 4 and 5, 78% of the Rincon area is dedicated to forest. The second largest use is pasture for grazing livestock (13.6%). Crop cultivation is relatively low (2.6%); however, there is a potential danger that it will increase over the years. The majority of the agricultural activity takes place on the coastal strip, outside the RFGD,

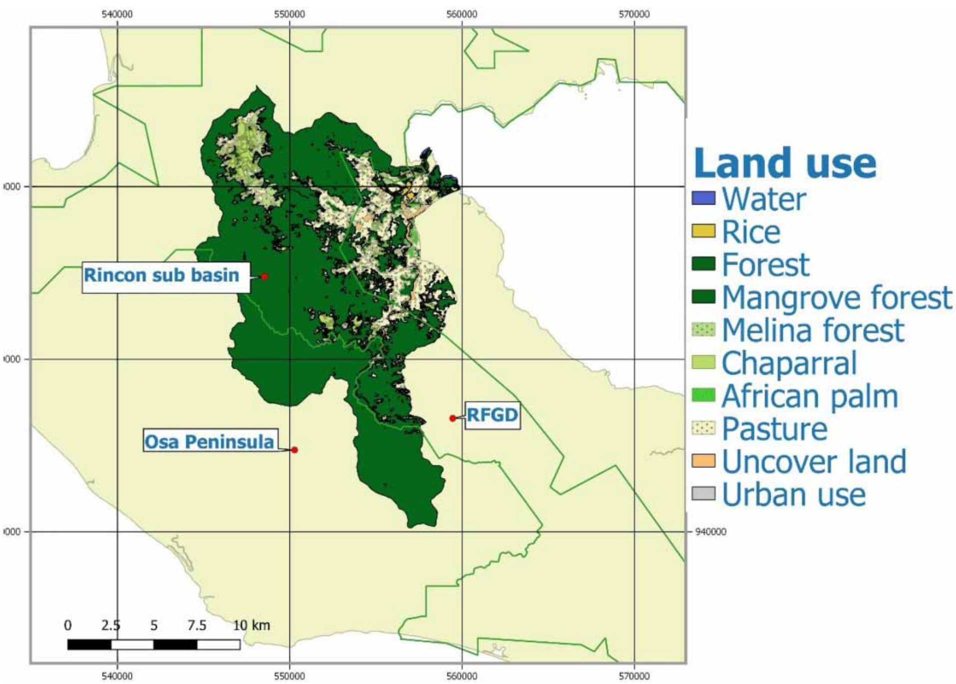

Figure 4 | Land-use evaluation at Rincon sub-basin. Please refer to the online version of this paper to see this figure in color: http://dx.doi.org/10.2166/ws.2019.079. *Source:* amended from Calvo-Brenes *et al.* (2016).

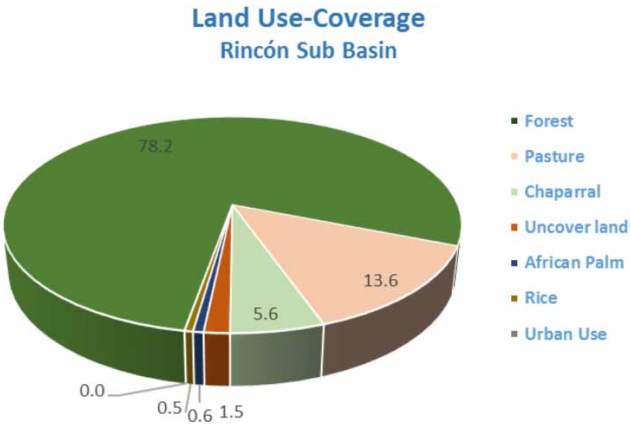

Figure 5 | Land use and coverages found in the Rincon sub-basin. *Source:* amended from Calvo-Brenes *et al.* (2016).

an area that represents 18.6% of the entire area of the sub-basin.

Other environmental variables

Table 4 displays other environmental variables required for the predictive model. Some of them may not change much in time, like soil texture or the slope; others will, like land use and human population density.

The average WQI measured in the lower area of the river was 85.4% (Table 3), which represents a water of incipient pollution (Class 2), according to the quality range classification used (Calvo-Brenes 2013). This class is good for the maintenance of aquatic flora and fauna, as well as for use in swimming activities with no risk to human health; therefore, this will be the baseline or minimum acceptable WQ. Table 5 shows that WQI predicted values using the two predictive models are 85.2% and 85.4% (Calvo-Brenes 2013). It is shown that the predictive values are within the boundaries of 7.2% model error in relation to the real values, which results bring confidence about using the model to predict future environmental variable changes.

Scenario analysis

During the different scenarios' analysis shown in Table 5, only one variable was changed at a time, while the others remained with the same initial values and the purpose was to evaluate how some changes in the environment may affect the WQ. It is possible to create infinitive scenarios, but the purpose was to evaluate some of them considering high values that may happen in the long term and available private land, specially the coastal zone where those changes may happen.

Table 4 | Environmental variables required for the predictive models

Variable	Value
Soil texture (%)	
Sand	8.64
Silt	28.97
Clay	62.39
Texture type	Clay
Slope (%)	
Maximum transversal	15.07
Maximum	26.5
Average transversal	8.91
Average	2.5
Other land use	
Riparian (meters)	93.23
Urbanism (%)	0
Perennial crops (%)	0.6
Flow rate (litres/second, G-4)	6,833
Density	
Human population (habitants/km^2)	0
Drainage (D_d)	6.1
Current (D_s)	0.000931
Order	4

Table 5 | Different scenarios created with two predictive tools

Condition	WQI		
	Model 1	Model 2	Class
Predicted WQI (%)	85.2	85.4	2
Population (hab/km^2)			
+1000	82.6	81.8	2
+5000	72.3	67.4	3
Chaparral			
(5.6 – 25) %	85.2	100.0	1 & 2
Pasture			
(13.6 – 25) %	91.7	85.4	1 & 2
Perennial crops			
(0.6 – 25) %	85.2	80.9	2

Note:

1. CONTAMINATION LEVELS:
None for Class 1 (blue); Low for Class 2 (green); Moderate for Class 3 (yellow); Severe for Class 4 (orange); Very severe for Class 5 (red)

The first scenario was obtained increasing the variable human population density from 0 (actual value) to 1,000 hab/km^2. Doing this, the original values of 85.2% and 85.4% (models 1 and 2) went down to 82.6% and 81.8%, respectively, even though quality classification did not change and remained as Class 2 (low contamination), which represents a good target. If this variable is increased to 5,000, then the new WQI decreases its original value to 72.3% and 67.4%, respectively. Under this new scenario, the WQ will change from Class 2 (low contamination) to 3 (moderate contamination). Therefore, increments in human population have a negative impact on WQ, according to both models, and the magnitude will depend on the variation in density size. SINAC has no control on this variable but it is important to measure the effect since this variable has a significant negative effect on the WQI. In past years, the Rincon area has experienced little change in population density; therefore, in the near future this is a variable of no concern.

If the environmental variables remain the same as the original values and the chaparral land use changes from its original 5.6% to 25%, there will be no change in WQ, according to model 1. But model 2 predicts an increase in quality to Class 1 (100%). That means that any increase in chaparral land use in Rincon may not change or may improve the WQI. Chaparral land use has no negative effects on WQ, according to both predictive models.

An increase in pasture land use, from its original 13.6% to 25%, shows an increase of WQ using model 1 (Class 1), but model 2 predicts that it will remain the same class (Class 2). Once again, WQ could remain the same or it could improve with increments in grass land use.

An increase in perennial crop land use from its actual 0.6% value to 25%, shows no change in WQ using model 1. On the other hand, model 2 shows a decrease of almost 5 percentage points, even though it is still Class 2 in this case.

CONCLUSIONS

Increments in human population density are not probable in the medium term, but the animal population has a negative impact on WQ as mentioned before. This situation is detected when fecal coliforms are high at a sampling point where there is no human population in the area. The source could be wildlife or livestock. The two models can predict the impact in WQ caused by human population only and the impact of the animal population was not considered.

Changes in pasture or chaparral land use does not affect the water quality. All the contrary occurs when land use is intended for agricultural purposes (model 2).

It is recommended that SINAC should increase the land-buying program inside the RFGD and this land be dedicated for forest use, to overcome possible extensive use of land in agricultural activities that may occur in time along the coastal strip, where SINAC has no control or even in private lands inside the RFGD. The government land in the RFGD should be dedicated to forest coverage, activity that is well documented for all the benefits caused in general (Calvo-Brenes 2013).

The use of environmental predictive models has proved to be an effective tool, according to this research, for government land-use regulation planning, for the establishment of integrated water resources management using different environmental components, such as land use inside a basin. It could also be a useful tool in the development of water quality restoration programs in rivers.

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