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Variation of population density on a beach: A simple analytical formulation

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ABSTRACT
Since the novel coronavirus was reported (December 2019), the virus spread rapidly breaking through frontiers and impacting almost all countries of the world. Tourism is one of the sectors that has been heavily affected by the crisis. Even though there are several protocols for tourism activities that were written for the austral summer season, at the present, physical distancing is considered an effective way to reduce the spread of the virus. Clear and simple public actions should be rapidly implemented by the authorities to minimize the number of people on the beach. For instance, increasing the number of accesses to the beaches, building parking lots adjacent to the farthest beaches, or opening coastal roads on the outskirts of town to expand usable beaches, would be some simple and direct measures to reduce the beach population density. A simple analytical formulation for assessing the percentage decrease of the static population density respect to the absolute maximum population density on a beach is described in this paper. The variables of this simple analytical tool are the instantaneous sea-level (tide), air temperature, and beach expansion. Beach expansion is the single and manageable variable of the formulation, and refers to the inclusion of some near or adjacent extension of beach. It is suggested that the expansion of beaches would be very useful not only for pandemic time but also for the new normality. An application of this methodology is presented in the municipality of La Costa, Argentina.

1. Introduction
Since the novel coronavirus was first reported in December of 2019 in Wuhan, China, the virus spread rapidly breaking through frontiers and reaching almost all the countries of the world. In this context, the World Health Organization (WHO) declared the outbreak of coronavirus disease (COVID-19) a Public Health Emergency of International Concern by January 2020, and a month later a Pandemic. Rapidly, researchers began to work to understand the transmission dynamics of the disease to provide insights into the epidemiological situation and identify the best control measures. Most local and national governments have taken unprecedented measures to control the epidemic spread, such as, mandatory lockdown (home isolation). By the first days of 2021, at least ten vaccines for severe acute respiratory syndrome–coronavirus 2 (SARS-CoV-2) have received full or limited approval for emergency use (Zimmwe et al., 2021) and vaccination programs are being conducted in many countries around the world. On the meantime, the WHO advice some simple precautions to prevent the spread of the virus, such as physical distancing, wearing a mask, keeping rooms well ventilated, avoiding crowds, among others (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public). The virus can remain viable and infectious in aerosol for hours and on surfaces up to days (Van Doremalen et al., 2020). In this way, significantly positive associations of high concentrations of air pollutants with confirmed cases (Zhu et al., 2020), provides insight into the environmental conditions for virus evolution. Although, there is no clear evidence that warmer weather conditions could decline COVID-19 (Baker et al., 2020), on the other side, a positive linear relationship was found between mean temperature and the number of confirmed cases but only below 3 °C (Xie and Zhu, 2020). Population immunity is a much more fundamental driver of pandemic invasion dynamic, even though climate could play a role modulating detailed aspects of the size and time scale within a particular location (Baker et al., 2020). Unprecedented policies were implemented to reduce as much as possible the...
virus transmission such as, closure of workplaces (except those considered essentials), schools, restaurants, bars, or clubs. Within these measures, the travel restriction and the general closure of international borders, impacted heavily on tourism economies during 2020.

For Latin America and the Caribbean this is the worst economic and social crisis experienced in decades with drop expected in the GDP rate by 9% (CEPAL, 2020). Tourism is one of the sectors that has been hit hardest by the crisis. The international tourism arrivals has decayed on average 74% compared to previous year due to massive drop in demand and travel restrictions (World Tourism Organization, 2021). The World Tourism Organization estimated losses in ~UDS 1.3 trillion in export revenues from international tourism. This perspective urged national and local governments to ideate new strategies to reopen the tourism industry and face the crisis.

There are several protocols for tourism activities written for the austral summer season, on the context of the pandemic. Particularly, Zielinski and Botero (2020) provided a scientific basis for understanding the key issues for beach tourism management in these circumstances. These include: risk perception, environmental considerations directly related to beaches and COVID-19, and management strategies designed to limit the risk of contagion on the beach. With regard to such strategies, physical distancing (joint with the use of masks and hygiene measures) is considered the simplest way to prevent virus transmission for the moment (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public). Consequently, clear and simple public actions should be rapidly implemented by the authorities to minimize the number of people on the beach at a certain time and place, commonly recognized as Beach User Density (BUD) measured in meters per user (Botero and da Silva, 2018). BUD allows beach managers to establish some actions such as: number and location of access, toilets and signage, potential risk area, among others. A similar tool for beach management is the Beach Carrying Capacity (BCC), defined as the relation between the beach occupation level and the surface available (da Silva, 2002). Although this tool seeks a balance between ecosystem resilience and tourist use while keeping the user’s comfort (Botero and da Silva, 2018), it also could be used as an evaluation strategy to avoid populated areas for a pandemic situation (Zielinski and Botero, 2020).

Huamantinco Cisneros et al. (2016) presented a methodology based on in-site information and video processing to estimate and evaluate the BCC and beach usage level in Monte Hermoso (Argentina), one of the most popular sites during summer vacation in this country. Nowadays, BCC is being reformulated to reduce the risk of contagion (Yepes, 2020). A realistic estimation of the BCC would constitute the cornerstone for beach management during the pandemic. In many places of the world, where beaches are public and completely open to the population, is practically impossible to limit access when the maxima BCC has been reached. Consequently, the governments of many coastal municipalities are working on opening up secluded or remote beaches, which are typically empty during the summer due to a lack of access roads or poor maintenance. This question then becomes immediately apparent: How much would BUD fall in crowded beaches after promoting less-known, alternative beaches?

For the purpose to give an answer to the above question, we developed a simple analytical formulation to illustrate the percentage decrease ($\Delta d_e$) of the static population density (d) respect to the absolute maximum population density on the beach ($d_{max}$). In general, $d_{max}$ depends on many environmental and social/anthropogenic variables (e.g. predominant weather, air and water temperature, wind intensity, tidal level, cloud cover, sand temperature, available beach length along shore, high and low season, weekday, weekend, or holyday, carnival week, and entertainment). Considering all these variables in a completely realistic analytical expression of $\Delta d_e \left(= \frac{d_{max} - d}{d_{max}} \times 100\right)$ would be highly complex. In order to develop a useful management tool, it was assumed that d depends only on two environmental variables (instantaneous sea-level height and air temperature), and one anthropic (or manageable) variable: expansion of available beach ($\Delta y$). This last quantity represents the increase of beach space laterally, produced for instance, by the inclusion of some near beach usually empty during the summer.

2. Methodology

Firstly, it is assumed that the population on the beach (N) during a typical summer day (windless, in rush hour, at a crowded sector of the coast), can be represented as a linear function of the air temperature ($T$):

$$N = \begin{cases} N_{max} - \Delta N (T_{UPPER} - T) & T_{LOWER} \leq T \leq T_{UPPER} \\ N_{max} & T > T_{UPPER} \end{cases}$$  \hspace{1cm} (1)

where $N_{max}$ is the absolute maximum population on the beach during the best moment of an excellent summer day, $\Delta N$ is the rate of population decreasing per each temperature degree (expressed in number of people/°C), and $T_{LOWER}$ and $T_{UPPER}$ the lower and upper limits for a specified temperature range. Secondly, it is assumed that $\Delta N$ is proportional to $N_{max}$:

$$\Delta N = \frac{N_{max}}{\alpha}$$  \hspace{1cm} (2)

$\alpha$ is an empirical constant which is used to represent the rate of population decreasing per each temperature degree. The bigger is $\alpha$, the smaller is $\Delta N$. $N_{max}$ and $\alpha$ are empirical quantities and could be estimated for a particular beach using a methodology similar, for instance, to Huamantinco Cisneros et al. (2016). From eqs. (1) and (2), results:

$$N = N_{max} \left[ 1 - \frac{(T_{UPPER} - T)}{\alpha} \right]$$  \hspace{1cm} (3)

The following numerical example is presented to illustrate the output of equation (3). If the population on the beach reaches the maximum (100%) during an excellent day, setting $T_{LOWER} = 20$ °C, $T_{UPPER} = 30$ °C, and $\alpha = 50$, the beach population will fall up 80% when T reaches $T_{LOWER}$. It is clear that, if T is lower than $T_{LOWER}$, the beach population drastically will fall to values significantly less than 80%. The settable parameter $\alpha$ depends on each particular location. The static population density (number of people sitting, standing or lying on the beach) per unit of area can be assessed as:

$$d = \frac{N}{xy}$$  \hspace{1cm} (4)

where x (m) and y (m) are the width and length of the beach, respectively, given by:

$$x = x_0 + \Delta x$$  \hspace{1cm} (5)

$$y = y_0 + \Delta y$$  \hspace{1cm} (6)

where $x_0$ is the minimum beach width in a month, i.e. is the distance between the bluff, escarpment or the dune foot at the backshore, and the line of the highest tidal level (spring tide); and $y_0$ is the length of the beach (it is assumed that the static population density d can be considered quite homogeneous or uniform in the area given by xy). In this work, it is assumed that x is only function of the sea-level due to the tide (atmospheric variables, as wind, are not taking into account because the concurrence of people to the beach considerably decreases during windy days or surge). $\Delta x$ and $\Delta y$ are variations of x and y, respectively. Then, the absolute maximum population density on the beach ($d_{max}$) is:

$$d_{max} = \frac{N_{max}}{x_0 y_0}$$  \hspace{1cm} (7)

Hourly sea-level heights, $z(t)$, with t time, can be easily predicted for a coastal location (Forerem, 1977; Pugh and Woodworth, 2014). In general, $z(t)$ is referred to a local tidal datum, i.e. the lowest astronomical tide level ($z_{LAT}$), and is greater than zero. Hourly sea level is
measured from the highest astronomical tide level ($z_{HAT}$), as follow:

$$\Delta z(t) = z_{HAT} - z(t)$$

(8)

then, if $z(t)$ is equal to $z_{LAT}$ or $z_{HAT}$, $\Delta z(t)$ will be maximum or zero, respectively; and if $z_{LAT} < z(t) < z_{HAT}$, $\Delta z(t)$ will be positive (Fig. 1). If the intertidal beach surface ($z_{LAT} < z(t) < z_{HAT}$) is considered approximately flat, with a uniform angle relative to $\beta$ ($s = \tan \beta$ is the mean beach slope, but for small $\beta$, $s$ is approximately equal to $\sin \beta$), the variation of beach width due to the tide ($\Delta x$) can be easily expressed as:

$$\Delta x = \frac{d \times \sin \beta}{s}$$

(9)

Therefore, $d$ can be easily computed for a particular instant of a day replacing equations (3), (5), (6) and (9) in (4):

$$d = \frac{N_{MAX} [1 - \frac{(T_{LOW}-T)}{\pi}] }{[x_o + \frac{\Delta z \times 100}{\pi}] (y_o + \Delta y)}$$

(10)

Finally, the percentual decreasing of $d$ respect to $d_{MAX}$ (eq. (7)) depends on $\Delta t$, $T$, and $\Delta y$, and can be estimated as:

$$\Delta d(t, T, \Delta y) = \frac{(d_{MAX} - d)}{d_{MAX}} \times 100 = \left\{ 1 - \frac{x_o \cdot y_o \left[ 1 - \frac{(T_{LOW}-T)}{\pi} \right]}{[x_o + \frac{\Delta z \times 100}{\pi}] \cdot (y_o + \Delta y)} \right\} \times 100$$

(11)

where $d$ depends on two environmental variables: $z(t)$ and $T$, and one anthropic (or manageable) variable: $\Delta y$. This last quantity represents the beach increase, for instance, produced by the inclusion of some near beach. $\Delta y$ can be seen as only one segment of the beach or as the sum of several segments of the beach located in the vicinity, but distributed on various locations around the main tourist settlement. In the last case:

$$\Delta y = \Delta y_1 + \Delta y_2 + \ldots + \Delta y_i + \ldots = \sum \Delta y_i$$

(12)

in which $\Delta y$ (or $\sum \Delta y_i$) can be directly expressed as a fraction of $y_o$, that is, $\Delta y = \gamma y_o$:

$$\Delta d(t, T, \gamma) = \frac{(d_{MAX} - d)}{d_{MAX}} \times 100 = \left\{ 1 - \frac{x_o \cdot y_o \left[ 1 - \frac{(T_{LOW}-T)}{\pi} \right]}{[x_o + \frac{\Delta z \times 100}{\pi}] \cdot (y_o + (1 + \gamma))} \right\} \times 100$$

(13)

As mentioned, it is very important to be able for evaluating the inverse problem i.e., how much should be $\gamma y_o$ (or $\sum \Delta y_i$) for decreasing $d_{MAX}$ a specific quantity $\Delta F(t, T, y)$? From equation (11), $\Delta y$ can be directly estimated for the maximum population density (i.e. $T > 30^\circ$ and $z(t) = z_{HAT}$):

$$\Delta y = \gamma y_o = \sum \Delta y_i = y_o \left[ \frac{\Delta d_o}{100 - \Delta d_o} \right]$$

(14)

To apply equation (11) or (13), $T_{UPPER}$ can be easily obtained from meteorological statistics, $x_o$ and $s$ can be estimated from historic beach profiles measured “in situ”, $z_{HAT}$ and $z(t)$ can be obtained from tidal tables, and $y_o$ is the desirable stretch of crowded beach to enlarge with a beach extension given by $\Delta y$. Finally, $t$ is the time, and $T$ the air temperature at $t$.

3. Results

From March to December 2020, many touristic activities were restricted in the world, and practically all these activities were forbidden in many provinces of Argentina, especially at the Buenos Aires Province coast. Nevertheless, as beach tourism is crucial for the economy of almost all Buenos Aires littoral departments, beaches were completely opened in December. The challenge for all of us (politicians and citizen working together) is to develop and implement viable solutions for the pandemic and the new normality.

3.1. Application example: La costa department, Buenos Aires Province, Argentina

This simple analytical formulation is applied to illustrate the temporal variability of the beach population density in the municipality of La Costa, located in the northeastern sector of Buenos Aires Province, Argentina (Fig. 2). It has almost one hundred kilometers of uninterrupted sandy beach and its main source of income is the summer tourism. The estimated stable population is 80,000 inhabitants for the year 2020 (INDEC, 2015). Last summer, before the COVID-19 pandemic, more than 1,300,000 tourists visited La Costa (https://www.telam.com.ar/notas/202002/428891-particle-de-la-costa-cantidad-turistas-enero.html). Strikingly, the percentage of La Costa’s beach harnessed by tourists is less than 50% of its total extension.

Average minimum and maximum air temperatures are 15 and 28 °C in summer in La Costa Department, but extreme temperatures up to 40 °C can be reached in December or January. Hot waves (i.e. daily maximum temperature is higher than 31 °C) often occur in January and can last 7 days (https://www.smn.gob.ar/estadisticas). Tides in this region are mixed semi-diurnal with a spring range of 1.69 m at Santa Teresita (http://www.hidro.gov.ar/oceanografia/Tmareas/BE_Mareas.asp). Beach profiles have been surveyed over last years at the Buenos Aires northeastern coast of Buenos Aires Province (Parker et al., 1978a, 1978b; Perillo, 1979; Bertola, 2006; Lopez and Marcomini, 2006, 2013; Alonso et al., 2018). The beaches generally have a dissipative profile with widths between 60 and 140 m (from the foredune to the LAT), with slopes lower than 2° ($s \sim 0.03$). A complete description of beach profiles in the region can be found in Marcomini et al. (2002). Using this information, and assuming for this application example $y_o = 6$ km, $x_o = 60$ m, $T_{UPPER} = 30^\circ C$, $T_{LOWER} = 20^\circ C$, $a = 50$, and $z_{HAT} = 1.87$ m, the eq. (11) for La Costa’s beaches can be expressed as:

$$\Delta d(t, T, \gamma) = \left\{ 1 - \frac{3.6 \times 10^7 \times y_o \left[ 1 - \frac{(T_{LOW}-T)}{\pi} \right]}{60 + \frac{1.82 \times 10^6}{10^4} \cdot (6 \times 10^3 + \Delta y)} \right\} \times 100$$

(15)

where $\Delta d_o(t, T, \gamma)$ is a linear function of $T$. The variation of $\Delta d_o$ with the tide, considering $1.63 m \geq z(t) \geq 0 m$, $T = 30^\circ C$, $\gamma = 0$ is presented in Fig. 3.a, and the variation of $\Delta d_o$ with $\gamma$, for $z(t) = 1.69$ m, $T = 30^\circ C$, $0 \leq \Delta y \leq 6$ km is deployed in Fig. 3.b.

Then Fig. 3 is used for analyzing some particular days in La Costa beaches. High- and low-tide predictions of 1.75 m (13:09) and 0.40 m (19:50), respectively, were published in the Tidal Tables predictions of

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Fig. 1. Sketch of the beach profile. LAT is the lowest astronomical tide level, and HAT is the highest astronomical tide level. The intertidal zone is pointed out in green, $\Delta z$ is the hourly sea-level (positive downwards) referred to HAT level, $\Delta x$ (in red) is the available beach width, and $\beta$ is a constant angle referred to the horizontal plane. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
Argentina for December 19, 2020 (http://www.hidro.gov.ar/oceano
grafia/Tmareas/RE_Mareas.asp). Logically the population density will
become maxima during the high-tide and conserving the same popula-
tion on the beach, the density will gradually decrease, around 40–50%,
due to the low-tide (Fig. 3a). The sunset was 20:43 on December 19,
2020, at La Costa Department. Similarly, on January 15, 2021, during
the peak of the high season, high- and low-tide of 1.76 m (11:01) and
0.36 m (17:54) are published in the Tidal Tables. While the weather can
be forecasted as much one week in advance, the tide and sunset times
can be predicted much more in advance because they have an astro-
nomical dependence. Then, authorities and coastal managers can make
a prevision about dates and times when the potential population density
will be maximum on the beach. These critical days, around the high-tide
time, will be the periods for the higher population density. Fig. 3 .b is
useful to determine the reduction in population density with the in-
crease of beach space. It is clearly appreciable that if, for instance, 2 km
of the beach was added to the system, it would produce a decrease of
around 25% to the maximum population density on the beach.

Considering that some syzygy high-tide times will occur during the
night-time, or during windy, cloudy or rainy days, the number of critical
periods, that is, lapses of maximum population density on the beach will
be significantly reduced. As explained above, all of them can be easily
predicted. But, when spring high-tides occur during excellent beach
days, authorities will have to make an effort to convince the tourist to
move to adjacent or near beaches, in order to reduce as much as possible,
the population density on centric beaches.

In order to further illustrate the variation in population density due
to tides on beaches of La Costa, Fig. 4 is presented. Photographs were
taken at a public beach located at Mar del Tuyú, with similar environ-
mental conditions (cloudless, pleasant air temperature, and windless
day) at different tidal stages. Low and high tide conditions can be seen in
Fig. 4a and 4 .b, respectively. The beach width is considerably reduced
from low to high tide and consequently, the population density
increased.
3.2. Utility and dissemination of the information provided by the developed formulation

It is important to remark that the results obtained by means of the developed formulation was not conceived to be used directly by the tourists. The presented analytical tool, with the integration of more specific information, was thought as a decision tool to be used by local authorities in the process of designing beach management strategies. Tidal tables, sunrise/sunset time tables, weather forecasts, and beach slopes are very useful to the coastal managers to determine the moments of maximum population density on beaches.

Some of the most commonly used and successful measures to manage beaches include, among others, a website to help the public plan their trip and find out what’s available before leaving home or to make the parking reservation in advance. In addition, a local beach ticket system to control the number of visitors using a mobile application could be implemented. Moreover, the information given by this analytical formulation could also be handy to predict the static population density of beach sectors that serve groups with different characteristics (i.e., areas reserved for people over 70 years of age).

The information obtained by the proposed analytical formulation could be easily processed, interpreted, mapped, and finally posted on a website by the authorities. For example, a real-time map indicating with a color palette the current and the predicted population density on a beach would be very convenient to schedule the day. In addition, a mobile application to select the nearest beach with very low, low or medium population density could be highly useful.

Higher tides can be predicted in advance because they have an astronomical origin. Then, the coastal managers can make a prevision about dates and times of maximum population density. Before these critical days, and taking into account the weather forecast, authorities could send a warning to the tourist (for instance, via text message) pointing out that in a determined date and time the beach width will be minimum and then, the density population will be likely maximum. Consequently, the tourists could plan to spend this particular day on a farther and quieter beach.

It is important to highlight that the presented formulation wouldn’t be very useful as an isolated measure. The developed analytical formulation is a guiding tool that does not replace the permanent monitoring of the beaches. In this sense, a systematic and integral monitoring plan and the implementation of more efficient diffusion media, supported by the different coastal municipalities, are mandatory to enhance the available tools and to develop new management models.

4. Discussion

Proactive actions are necessary, not only for the current emergency but also for the so-called “new normality”. It is imperative to implement policies to attract more tourists, but, at the same time, it is mandatory to diminish the population density on the beaches. This last is to avoid the virus spreading but, principally, to improve the quality of the touristic offer. Some simple and economic actions can be carried out to diminish the population density on the beach. For instance, increasing the number of accesses to the beach, building parking lots adjacent to the farthest beaches, and opening of coastal roads on the outskirts of town to expand usable beaches, are some tasks that could be developed by municipal authorities and carried out by local workers. If the beach extension was expanded, it would reduce the population density on the main overcrowded beaches. Some similar actions has been applied in the last 25 years in Portugal, where a shoreline management plan was applied and a remarkable improvement was seen with the beach carrying capacity playing a crucial role (da Silva et al., 2020). This Portuguese experience pointed the importance of beach zoning according to accessibility and the perceptions and expectations of beach users, remarking the vital of good data and monitoring protocols. In this sense, our formulation, tidal tables, sunrise/sunset time tables, weather forecasts, and all scientific and technical information available will let the coastal managers tools to determine the most effective measures to diminish population density on beaches.

Some factors could actually be as important as the utilisable sand area, for instance, the inhomogeneous distribution of tourist all over the beach. da Silva (2002) pointed out some factors that affect the beach user density, for instance, beach topography, location of beach accessibility, parking availability and, in particular, the perception of users. For example, over several beaches of Portugal, da Silva (2002) explained that most of beach users prefer to stay to less than 250 m from formal access to the beach and less than 50 m from the coastline. This last was also observed in Barcelona’s beaches by means of long term video monitoring, that even through the maximum occupation periods, the region close to the seawater showed the highest concentration, meanwhile the beach far from the shoreline wasn’t completely occupied (Guillén et al., 2008). In this way, it is also very important to consider some social factors, for example: beach user preferences, reasons for beach choice, and perceptions. Botero et al. (2013), by means of questionnaire surveys, found that the proximity, cleanliness and facilities were the main preferences for the beach selection. Besides, this study revealed the importance of the particular perception of the “beach atmosphere” of each group of people, changing remarkably from Europe through Latin America.

The presented formulation was developed to quantify the BUD decreasing in crowded beaches as a function of a determined extension of beach (Δy) incorporated to the touristic offer. Local authorities should innovate and implement attractive strategies to tempt tourists to move to new areas, to educate (but not to impose) to use of the entire beach wide keeping an appropriate physical distancing, and to wear masks during the whole permanence on the beach. It is very important to
remark that if sanitary measures were omitted or relaxed for just one day, the consequences on the population health could be drastic. The application of our formulation, complemented with some of the more popular nautical publications (tidal tables and sunrise/sunset time tables, all of them available on the web) will help the authorities to plan an adequate strategy to avoid people’s concentration on beach. On the other hand, some preventive measures can be programmed well in advance. An ensemble of climatological models can be used to estimate the seasonal climate some months in advance. For instance, the mission of the International Research Institute (IRI) for Climate and Society is to enhance society’s capability to understand, anticipate and manage the impacts of climate in order to improve human welfare and the environment, especially in developing countries (https://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts/). This product can be used to know in advance if the summer will be warmer or colder, or drier or rainier than a regular summer for a particular region of the world. This information is very useful to obtain a preliminary climate forecast and, consequently, for anticipating the concurrence of tourism to the main centers.

It was normally accepted that an extremely crowded beach is synonymous of successful touristy summer season. But now, the indicators to measure tourism success should be reformulated. The reduction of population on crowded beaches is really a challenge in many places of the world. This challenge is particularly major in South America, because there is a lack of elemental information about the relationship among basic environmental parameters, for instance, the air temperature and wind intensity, and the population density on the beach. In Argentina, for instance, there is an absolute absence of beach management tools and indices, like Beach Carrying Capacity, for the main tourist destinations of the coast of the Buenos Aires province. A plan for monitoring basic ocean and meteorological parameters (for example, wave parameters, sea temperature, wind intensity, air temperature, cloud cover) and the implementation of a methodology for systematic surveying the population on the beach is mandatory for taking decisions and for planning strategies. For this last issue, the potentially valuable data source to infer human mobility with passively generated mobile phone data was demonstrated (Oliver et al., 2020), which could be used as a beach management tool (Merrill et al., 2020). BUD could be achieved by means of the capabilities of Argus video-cameras to record multi-purpose information video processing real-time data (Guillén et al., 2008; Huamantinco Cisneros et al., 2016; Jiménez et al., 2007).

Finally, as a consequence of the perceived risk of the pandemic, some tourists are being tempted to choose rural and natural beaches less congested than urban beaches, resulting in two emerging problems: this beaches are more susceptible to environmental impacts and they need for public infrastructure and facilities to cope with the demand (Zielinski and Botero, 2020). Some solutions could be projected in different scenarios in terms of the epidemic evolution and the social perception of it. In order to rethink beach tourism future, Botero et al. (2020) proposed strategies to reflection on the future beach tourism, in which an optimistic scenario posed a new concept of tourism, converting the beaches in a place where to meet the nature, the culture and people, against only a socializing space. This may lay in an opportunity to turn into a more sustainable tourism (Ioannides and Gyimothy, 2020), but only if a real decision of governments policies points not to bet into the already know massive sun tourism.

5. Conclusion

An analytical formulation developed to illustrate the percentage decrease ($\Delta d_0$) of the static population density respect to the absolute maximum population density on a beach was presented in this paper. In this formulation, $\Delta d_0$ depends on the instantaneous sea-level (tide), air temperature, and beach expansion ($\Delta y$), this last produced by the inclusion of some near or adjacent extension of beach. This tool was applied to illustrate the occurrence of cases of maximum beach population density in the municipality of La Costa, Argentina (Fig. 2). In this example, if 2 km of the beach were added to a beach system of 6 km long, it would produce a reduction of around 25% to the maximum population density. It is suggested that increasing the number of accesses to the beaches, building parking lots adjacent to the farthest beaches, and/or opening coastal street on the outskirts of town, could be some simple and direct measures to reduce the beach population density. All these tasks could be projected by local authorities and relatively quickly executed by local workers. The promotion of alternative beaches would be very useful not only for pandemic time but also for the new normality. The information obtained by the proposed analytical formulation could be easily processed and shared on a website by the authorities. Lastly, this formulation with the integration of more specific information, constitutes a decision tool to be used by local authorities in the process of designing beach strategies on management.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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