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On Soft Generalized Preregular Closed and Open Sets in Soft Topological Spaces

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Abstract

In this paper, we define soft generalized preregular closed and open sets in soft topological spaces which are defined over an initial universe with a fixed set of parameters and we investigate some basic properties of these concepts. Also we discuss their relationships with different types of subsets of soft topological spaces with the help of counterexamples.

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1 Introduction

Molodtsov [1] initiated a novel concept of soft set theory, which is a completely new approach for modeling vagueness and uncertainty. He [1] established the fundamental results of this new theory and successfully applied the soft set theory into several directions, such as smoothness of functions, operations research, Riemann integration, game theory, theory of probability and so on. Maji et al. [2] defined and studied several basic notions of soft set theory. Shabir and Naz [3] introduced the soft topological spaces which are defined over an initial universe with a fixed set of parameters and studied some basic notions of soft topological spaces such as soft open and closed sets, soft subspace, soft closure, soft neighbourhood of a point, soft separation axioms. Later Aygünoğlu and Aygün [4], Hussain and Ahmad [5] and Zorlutuna et al. [6] continued to study the properties of soft topological spaces.

Recently, weak forms of soft open sets were studied. Chen [7] introduced the concept of soft semi-open sets in soft topological spaces. Kandil et al. [8] introduced the notions of γ-operation, pre-open soft sets, α-open soft sets, semi-open soft sets and β-open soft sets in soft topological spaces. The authors studied the relations between these different types of subsets of soft topological spaces. Kannan [9] defined soft generalized closed and open sets in soft topological spaces. He studied their some properties. Also he showed that every soft closed set is soft generalized closed. After then Yüksel et al. [10] defined soft regular generalized closed and open sets in soft topological spaces. Also they investigated behavior relative to union, intersection and soft subspaces of soft regular generalized closed sets. They showed that every soft generalized closed set is soft regular generalized closed.

In the present paper, we define soft generalized preregular closed sets which are weaker form of the above mentioned generalizations such as soft generalized closed set and soft regular generalized closed set and study the properties of them in soft topological spaces. Then we discuss their relationships with different types of subsets of soft topological spaces with the help of counterexamples. Also we introduce soft generalized preregular open sets in soft topological spaces and some basic properties of them. We introduce these concepts in soft topological spaces which are defined over an initial universe with a fixed set of parameters.

2 Preliminaries

Let X be an initial universe set and E be the set of all possible parameters with respect to X. Parameters are often attributes, characteristics or properties of the objects in X. Let $P(X)$ denote the power set of X. Then a soft set over X is defined as follows.

Definition 2.1 *[1] A pair (F, A) is called a soft set over X where $A \subseteq E$ and $F : A \longrightarrow P(X)$ is a set valued mapping. In other words, a soft set over X is a parameterized family of subsets of the universe X. For $\forall \varepsilon \in A$, $F(\varepsilon)$ may be considered as the set of ε-approximate elements of the soft set (F, A). It is worth noting that $F(\varepsilon)$ may be arbitrary. Some of them may be empty, and some may have nonempty intersection.*

Definition 2.2 *[2] A soft set (F, A) over X is said to be a null soft set denoted by Φ if for all $e \in A$, $F(e) = \emptyset$. A soft set (F, A) over X is said to be an absolute soft set denoted by $\widetilde{A}$ if for all $e \in A$, $F(e) = X$.*

Definition 2.3 *[3] Let Y be a nonempty subset of X, then $\widetilde{Y}$ denotes the soft set (Y, E) over X for which $Y(e) = Y$, for all $e \in E$. In particular, (X, E) will be denoted by $\widetilde{X}$.*

Definition 2.4 *[2] For two soft sets (F, A) and (G, B) over X, we say that (F, A) is a soft subset of (G, B) if $A \subseteq B$ and for all $e \in A$, $F(e)$ and $G(e)$ are identical approximations. We write $(F, A) \sqsubseteq (G, B)$. (F, A) is said to be a soft super set of (G, B), if (G, B) is a soft subset of (F, A). We denote it by $(G, B) \sqsubseteq (F, A)$. Then (F, A) and (G, B) are said to be soft equal if (F, A) is a soft subset of (G, B) and (G, B) is a soft subset of (F, A).*

Definition 2.5 *[2] The union of two soft sets (F, A) and (G, B) over X is the soft set (H, C), where $C = A \cup B$ and for all $e \in C$, $H(e) = F(e)$ if $e \in A - B$, $G(e)$ if $e \in B - A$, $F(e) \cup G(e)$ if $e \in A \cap B$. We write $(F, A) \sqcup (G, B) = (H, C)$. [11] The intersection (H, C) of (F, A) and (G, B) over X, denoted $(F, A) \sqcap (G, B)$, is defined as $C = A \cap B$, and $H(e) = F(e) \cap G(e)$ for all $e \in C$.*

Definition 2.6 *[3] The difference (H, E) of two soft sets (F, E) and (G, E) over X, denoted by $(F, E) - (G, E)$, is defined as $H(e) = F(e) - G(e)$ for all $e \in E$.*

Definition 2.7 *[3] The relative complement of a soft set (F, E) is denoted by $(F, E)^c$ and is defined by $(F, E)^c = (F^c, E)$ where $F^c : E \longrightarrow P(X)$ is a mapping given by $F^c(e) = X - F(e)$ for all $e \in E$.*

Definition 2.8 *[3] Let $\widetilde{\tau}$ be the collection of soft sets over X, then $\widetilde{\tau}$ is said to be a soft topology on X if*

(1) $\Phi, \widetilde{X} \in \widetilde{\tau}$
(2) If (F, E), $(G, E) \in \widetilde{\tau}$, then $(F, E) \sqcap (G, E) \in \widetilde{\tau}$
(3) If $\{(F_i, E)\}_{i \in I} \in \widetilde{\tau}$, $\forall i \in I$, then $\sqcup_{i \in I}(F_i, E) \in \widetilde{\tau}$.

The pair $(X, \widetilde{\tau})$ is called a soft topological space. Every member of $\widetilde{\tau}$ is called a soft open set. A soft set (F, E) is called soft closed in X if $(F, E)^c \in \widetilde{\tau}$.

Definition 2.9 *Let $(X, \widetilde{\tau})$ be a soft topological space over X and (F, E) be a soft set over X.*

(1) [3] The soft closure of (F, E) is the soft set $(F, E)^{-} = \cap\{(G, E) : (G, E)$ is soft closed and $(F, E) \sqsubseteq (G, E)\}$.

(2) [5] The soft interior of (F, E) is the soft set $(F, E)^{\circ} = \cup\{(H, E) : (H, E)$ is soft open and $(H, E) \sqsubseteq (F, E)\}$.

Clearly, $(F, E)^{-}$ is the smallest soft closed set over X which contains (F, E) and $(F, E)^{\circ}$ is the largest soft open set over X which is contained in (F, E).

Definition 2.10 *[8] Let $(X, \widetilde{\tau})$ be a soft topological space. A soft set (F, E) is called soft preopen set in X if $(F, E) \sqsubseteq ((F, E)^{-})^{\circ}$. The relative complement of a soft preopen set is called a soft preclosed set.*

It is obvious that every soft closed set is soft preclosed.

Definition 2.11 *Let $(X, \widetilde{\tau})$ be a soft topological space over X and (F, E) be a soft set over X.*

(1) [8] The soft preclosure of (F, E) is the soft set $(F, E)^{-p} = \cap\{(G, E) : (G, E)$ is soft preclosed and $(F, E) \sqsubseteq (G, E)\}$.

(2) [8] The soft preinterior of (F, E) is the soft set $(F, E)^{\circ p} = \cup\{(H, E) : (H, E)$ is soft preopen and $(H, E) \sqsubseteq (F, E)\}$.

Clearly, $(F, E)^{-p}$ is the smallest soft preclosed set over X which contains (F, E) and $(F, E)^{\circ p}$ is the largest soft preopen set over X which is contained in (F, E).

Theorem 2.12 *[8] Let $(X, \widetilde{\tau})$ be a soft topological space over X and (F, E), (G, E) are soft sets over X. Then*

(1) $\Phi^{-p} = \Phi$ *and* $(\widetilde{X})^{-p} = \widetilde{X}$.
(2) $(F, E) \sqsubseteq (F, E)^{-p}$.
(3) $((F, E)^{-p})^{-p} = (F, E)^{-p}$.
(4) $(F, E) \sqsubseteq (G, E)$ *implies* $(F, E)^{-p} \sqsubseteq (G, E)^{-p}$.
(5) $(F, E)^{-p} \sqcup (G, E)^{-p} \sqsubseteq ((F, E) \sqcup (G, E))^{-p}$.
(6) $((F, E) \sqcap (G, E))^{-p} \sqsubseteq (F, E)^{-p} \sqcap (G, E)^{-p}$.

Theorem 2.13 *[8] Let $(X, \widetilde{\tau})$ be a soft topological space over X and (F, E), (G, E) are soft sets over X. Then*

(1) $\Phi^{\circ p} = \Phi$ *and* $(\widetilde{X})^{\circ p} = \widetilde{X}$.
(2) $(F, E)^{\circ p} \sqsubseteq (F, E)$.
(3) $((F, E)^{\circ p})^{\circ p} = (F, E)^{\circ p}$.
(4) $(F, E) \sqsubseteq (G, E)$ *implies* $(F, E)^{\circ p} \sqsubseteq (G, E)^{\circ p}$.
(5) $((F, E) \sqcap (G, E))^{\circ p} \sqsubseteq (F, E)^{\circ p} \sqcap (G, E)^{\circ p}$.
(6) $(F, E)^{\circ p} \sqcup (G, E)^{\circ p} \sqsubseteq ((F, E) \sqcup (G, E))^{\circ p}$.

Theorem 2.14 *[8] Let $(X, \widetilde{\tau})$ be a soft topological space and (F, E) be a soft set over X. Then*

(1) $((F,E)^c)^{\circ p} = ((F,E)^{-p})^c$.
(2) $((F,E)^c)^{-p} = ((F,E)^{\circ p})^c$.

Definition 2.15 *[9] Let $(X, \widetilde{\tau})$ be a soft topological space. A soft set (F, E) is called soft generalized closed (briefly soft g-closed) in X if $(F,E)^- \sqsubseteq (G,E)$ whenever $(F,E) \sqsubseteq (G,E)$ and (G,E) is soft open in X.*

Theorem 2.16 *[9] Let $(X, \widetilde{\tau})$ be a soft topological space and (F, E) a soft set over X. If (F,E) is soft closed, then (F,E) is soft g-closed.*

Definition 2.17 *[10] Let $(X, \widetilde{\tau})$ be a soft topological space. A soft set (F, E) is called soft regular open (soft regular closed) in X if $(F,E) = ((F,E)^-)^\circ$ $((F,E) = ((F,E)^\circ)^-)$.*

Remark 2.18 *[10] Every soft regular open set in a soft topological space $(X, \widetilde{\tau})$ is soft open.*

Definition 2.19 *[10] Let $(X, \widetilde{\tau})$ be a soft topological space. A soft set (F, E) is called soft regular generalized closed (soft rg-closed) in X if and only if $(F,E)^- \sqsubseteq (G,E)$ whenever $(F,E) \sqsubseteq (G,E)$ and (G,E) is soft regular open in X.*

Theorem 2.20 *[10] Let $(X, \widetilde{\tau})$ be a soft topological space and (F, E) a soft set over X. If (F,E) is soft g-closed, then (F,E) is soft rg-closed.*

3 Basic Properties of Soft Generalized Preregular Closed Sets

Definition 3.1 *Let $(X, \widetilde{\tau})$ be a soft topological space. A soft set (F, E) is called soft generalized preregular closed (soft gpr-closed) in X if $(F,E)^{-p} \sqsubseteq (G,E)$ whenever $(F,E) \sqsubseteq (G,E)$ and (G,E) is soft regular open in X.*

By using definitions, it is obvious that every soft regular closed set is soft preclosed and every soft preclosed set is soft gpr-closed. The examples given below show that the converses of this implications are not true.

Example 3.2 *Let $X = \{x_1, x_2\}$, $E = \{e_1, e_2\}$ and*
$\widetilde{\tau} = \{\Phi, \widetilde{X}, (F_1,E), (F_2,E), (F_3,E), (F_4,E), (F_5,E)\}$ *where*
$F_1(e_1) = \{x_2\},\ F_1(e_2) = \{x_2\}$,
$F_2(e_1) = \{x_1\},\ F_2(e_2) = \emptyset$,

$F_3(e_1) = X,\ F_3(e_2) = \{x_2\}$,
$F_4(e_1) = \{x_2\},\ F_4(e_2) = \emptyset$,
$F_5(e_1) = X,\ F_5(e_2) = \emptyset$.

Then $(X, \widetilde{\tau})$ is a soft topological space over X. Let (H, E) be a soft set over X such that $H(e_1) = \{x_1\},\ H(e_2) = X$. Clearly, (H, E) is soft gpr-closed in $(X, \widetilde{\tau})$, but it is not soft regular closed.

Example 3.3 *Let $X = \{x_1, x_2\}$ and $E = \{e_1, e_2\}$. Let us take the soft topology $\widetilde{\tau}$ on X in Example 3.2. Let (G, E) be a soft set over X such that $G(e_1) = X,\ G(e_2) = \{x_2\}$. Clearly, (G, E) is soft gpr-closed in $(X, \widetilde{\tau})$, but it is not soft preclosed.*

Theorem 3.4 *Every soft regular generalized closed (soft rg-closed) set in a soft topological space $(X, \widetilde{\tau})$ is soft generalized preregular closed (soft gpr-closed).*

Proof. Let (F, E) be a soft regular generalized closed set in X. Suppose that $(F, E) \sqsubseteq (G, E)$, where (G, E) is soft regular open. Since (F, E) is soft regular generalized closed, then $(F, E)^- \sqsubseteq (G, E)$. Since every soft closed set is soft preclosed, $(F, E)^{-p} \sqsubseteq (F, E)^-$. Therefore $(F, E)^{-p} \sqsubseteq (G, E)$. Hence (F, E) is a soft generalized preregular closed set.

The following example shows that the converse of the above theorem is not true.

Example 3.5 *Let $X = \{x_1, x_2\}$, $E = \{e_1, e_2\}$ and $\widetilde{\tau} = \{\Phi, \widetilde{X}, (F_1, E), (F_2, E), (F_3, E)\}$ where*
$F_1(e_1) = \{x_1\},\ F_1(e_2) = \{x_1\}$,
$F_2(e_1) = \{x_2\},\ F_2(e_2) = \emptyset$,
$F_3(e_1) = X,\ F_3(e_2) = \{x_1\}$.

Then $(X, \widetilde{\tau})$ is a soft topological space over X. Let (H, E) be a soft set over X such that $H(e_1) = \{x_1\},\ H(e_2) = \emptyset$. Clearly, (H, E) is soft gpr-closed in $(X, \widetilde{\tau})$, but it is not soft rg-closed.

From [9], [10] and Theorem 3.4, we have implications as shown in Figure-1 for a soft topological space $(X, \widetilde{\tau})$. These implications are not reversible.

$$\text{soft closed set} \longrightarrow \text{soft g-closed set} \longrightarrow \text{soft rg-closed set} \longrightarrow \text{soft gpr-closed set} \quad (1)$$

Figure-1

Theorem 3.6 *Let $(X, \widetilde{\tau})$ be a soft topological space and (F, E) a soft set over X. If (F, E) is soft regular open and soft gpr-closed, then (F, E) is soft preclosed and hence soft clopen.*

Proof. If (F, E) is soft regular open and soft gpr-closed, then $(F, E)^{-p} \sqsubseteq (F, E)$. This implies (F, E) is soft preclosed. Since every soft preclosed and soft open set is soft closed, hence (F, E) is soft clopen.

Remark 3.7 *The union of two soft gpr-closed sets is generally not a soft gpr-closed set.*

Example 3.8 *Let $X = \{x_1, x_2\}$ and $E = \{e_1, e_2\}$. Let us take the soft topology $\widetilde{\tau}$ on X in Example 3.5. Let (H, E) and (G, E) be two soft sets over X such that $H(e_1) = \{x_1\},\ H(e_2) = \emptyset$ and $G(e_1) = \emptyset,\ G(e_2) = \{x_1\}$. Clearly, (H, E) and (G, E) are soft gpr-closed sets in $(X, \widetilde{\tau})$ but $(H, E) \sqcup (G, E)$ is not a soft gpr-closed set.*

Remark 3.9 *The intersection of two soft gpr-closed sets is generally not a soft gpr-closed set.*

Example 3.10 *Let $X = \{x_1, x_2\}$ and $E = \{e_1, e_2\}$. Let us take the soft topology $\widetilde{\tau}$ on X in Example 3.2. Let (H, E) and (G, E) be two soft sets over X such that $H(e_1) = X,\ H(e_2) = \{x_2\}$ and $G(e_1) = \{x_2\},\ G(e_2) = X$. Clearly, (H, E) and (G, E) are soft gpr-closed sets in $(X, \widetilde{\tau})$ but $(H, E) \sqcap (G, E)$ is not a soft gpr-closed set.*

Theorem 3.11 *Let $(X, \widetilde{\tau})$ be a soft topological space and (F, E) be a soft set over X. If a soft set (F, E) is soft gpr-closed, then $\overline{(F, E)}^{p} - (F, E)$ contains only null soft regular closed set.*

Proof. Suppose that (F, E) is soft gpr-closed. Let (H, E) be a soft regular closed subset of $\overline{(F, E)}^{p} - (F, E)$. Then $(H, E) \sqsubseteq \overline{(F, E)}^{p} \sqcap (F, E)^c$ and so $(F, E) \sqsubseteq (H, E)^c$. Since (F, E) is a soft gpr-closed set and $(H, E)^c$ is soft regular open, we obtain $\overline{(F, E)}^{p} \sqsubseteq (H, E)^c$. Consequently $(H, E) \sqsubseteq (\overline{(F, E)}^{p})^c$. We have already $(H, E) \sqsubseteq \overline{(F, E)}^{p}$. Hence we obtain $(H, E) \sqsubseteq \overline{(F, E)}^{p} \sqcap (\overline{(F, E)}^{p})^c = \Phi$. This shows $(H, E) = \Phi$. Therefore $\overline{(F, E)}^{p} - (F, E)$ contains only null soft regular closed set.

Reverse implication does not hold.

Example 3.12 *Let $X = \{x_1, x_2\}$ and $E = \{e_1, e_2\}$. Let us take the soft topology $\widetilde{\tau}$ on X and the soft set (F_2, E) in Example 3.5. We have $(F_2, E)^{-p} - (F_2, E)$ contains only null soft regular closed set. But (F_2, E) is not a soft gpr-closed set in $(X, \widetilde{\tau})$.*

Theorem 3.13 *Let $(X, \tilde{\tau})$ be a soft topological space over X and (F, E) be a soft gpr-closed set in X. (F, E) is soft preclosed if and only if $\overline{(F, E)}^{p} - (F, E)$ is soft regular closed.*

Proof. Let (F, E) be a soft gpr-closed set. If (F, E) is soft preclosed, then $\overline{(F, E)}^{p} = (F, E)$. So $\overline{(F, E)}^{p} - (F, E) = \Phi$ which is soft regular closed.

Conversely, suppose that $\overline{(F, E)}^{p} - (F, E)$ is soft regular closed. Since (F, E) is soft gpr-closed, then $\overline{(F, E)}^{p} - (F, E) = \Phi$. That is $\overline{(F, E)}^{p} = (F, E)$. Hence (F, E) is soft preclosed.

Theorem 3.14 *Let $(X, \tilde{\tau})$ be a soft topological space, (F, E) and (G, E) are soft sets over X. If (F, E) is soft gpr-closed and $(F, E) \sqsubseteq (G, E) \sqsubseteq \overline{(F, E)}^{p}$, then (G, E) is soft gpr-closed.*

Proof. Let $(G, E) \sqsubseteq (H, E)$ where (H, E) is soft regular open. Then $(F, E) \sqsubseteq (G, E)$ implies $(F, E) \sqsubseteq (H, E)$. Since (F, E) is soft gpr-closed, $\overline{(F, E)}^{p} \sqsubseteq (H, E)$. $(G, E) \sqsubseteq \overline{(F, E)}^{p}$ implies $\overline{(G, E)}^{p} \sqsubseteq \overline{(F, E)}^{p}$. Thus $\overline{(G, E)}^{p} \sqsubseteq (H, E)$ and this shows that (G, E) is soft gpr-closed.

4 Soft Generalized Preregular Open Sets

Definition 4.1 *Let $(X, \tilde{\tau})$ be a soft topological space over X. A soft set (F, E) is called soft generalized preregular open (soft gpr-open) in X if and only if $(F, E)^c$ is soft gpr-closed.*

Theorem 4.2 *A soft set (F, E) is soft gpr-open in a soft topological space $(X, \tilde{\tau})$ if and only if $(H, E) \sqsubseteq (F, E)^{\circ p}$ whenever (H, E) is soft regular closed in X and $(H, E) \sqsubseteq (F, E)$.*

Proof. Suppose that (H, E) is soft regular closed and $(H, E) \sqsubseteq (F, E)$ implies $(H, E) \sqsubseteq (F, E)^{\circ p}$. Let $(F, E)^c \sqsubseteq (G, E)$ where (G, E) is soft regular open. Then $(G, E)^c \sqsubseteq (F, E)$ where $(G, E)^c$ is soft regular closed. By hypothesis $(G, E)^c \sqsubseteq (F, E)^{\circ p}$. That is $((F, E)^{\circ p})^c \sqsubseteq (G, E)$. Equivalently $\overline{((F, E)^c)}^{p} \sqsubseteq (G, E)$. Thus $(F, E)^c$ is soft gpr-closed. Hence we obtain (F, E) is soft gpr-open.

Conversely, suppose that (F, E) is soft gpr-open, $(H, E) \sqsubseteq (F, E)$ and (H, E) is soft regular closed. Then $(H, E)^c$ is soft regular open. Then $(F, E)^c \sqsubseteq (H, E)^c$. Since $(F, E)^c$ is soft gpr-closed, $\overline{((F, E)^c)}^{p} \sqsubseteq (H, E)^c$. Therefore $(H, E) \sqsubseteq (\overline{((F, E)^c)}^{p})^c = (F, E)^{\circ p}$.

Theorem 4.3 *Let $(X, \tilde{\tau})$ be a soft topological space, (F, E) and (G, E) soft sets over X. If (F, E) is soft gpr-open in X and $(F, E)^{\circ p} \sqsubseteq (G, E) \sqsubseteq (F, E)$, then (G, E) is soft gpr-open.*

Proof. $(F,E)^{\circ p} \sqsubseteq (G,E) \sqsubseteq (F,E)$ implies $(F,E)^c \sqsubseteq (G,E)^c \sqsubseteq ((F,E)^{\circ p})^c$. That is, $(F,E)^c \sqsubseteq (G,E)^c \sqsubseteq ((F,E)^c)^{-p}$. Since $(F,E)^c$ is soft gpr-closed, by Theorem 3.14, $(G,E)^c$ is soft gpr-closed and (G,E) is soft gpr-open.

Theorem 4.4 *Let $(X,\widetilde{\tau})$ be a soft topological space and (F,E) be a soft set over X. If a soft set (F,E) is soft gpr-closed in X, then $(F,E)^{-p} - (F,E)$ is soft gpr-open.*

Proof. Let (F,E) be soft gpr-closed and (H,E) be soft regular closed such that $(H,E) \sqsubseteq (F,E)^{-p} - (F,E)$. Then by Theorem 3.11, $(H,E) = \Phi$ and hence $(H,E) \sqsubseteq ((F,E)^{-p} - (F,E))^{\circ p}$. Hence we obtain that $(F,E)^{-p} - (F,E)$ is soft gpr-open by Theorem 4.2.

The converse of this theorem is not true in general as can be seen from the following example.

Example 4.5 *Let $X = \{x_1, x_2\}$ and $E = \{e_1, e_2\}$. Let us take the soft topology $\widetilde{\tau}$ on X and the soft set (F_2,E) in Example 3.5. We have $(F_2,E)^{-p} - (F_2,E)$ is a soft gpr-open set. But (F_2,E) is not a soft gpr-closed set in $(X,\widetilde{\tau})$.*

5 Conclusion

In the present study, we have introduced soft generalized preregular closed and open sets in soft topological spaces which are defined over an initial universe with a fixed set of parameters. We have presented its fundamental properties with the help of some counterexamples. In future these findings may be extended to new types of soft generalized closed and open sets in soft topological spaces. Further research is being carried out a general framework for their applications in practical life.

Competing interests. The authors declare that they have no competing interests.

Author contributions. All authors contributed equally and significantly in writing this paper.

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