ON PRE GENERALIZED $b$-CLOSED MAP IN TOPOLOGICAL SPACES

S. Sekar$^1$ $^\S$, R. Brindha$^2$

$^1$Department of Mathematics  
Government Arts College (Autonomous)  
Salem, 636 007, Tamil Nadu, INDIA  

$^2$Department of Mathematics  
King College of Technology  
Namakkal, 637 020, Tamil Nadu, INDIA

Abstract: In this paper, we introduce a new class of pre generalized $b$-closed map in topological spaces (briefly $pgb$-closed map) and study some of their properties as well as inter relationship with other closed maps.

AMS Subject Classification: 54C05, 54C08, 54C10

Key Words: $pgb$-closed set, $b$-closed map, $gb$-closed map, $rgb$-closed map and $gp^*$-closed map

1. Introduction

Different types of Closed and open mappings were studied by various researchers. In 1996, Andrijevic introduced new type of set called $b$-open set. A.A.Omari and M.S.M. Noorani [1] introduced and studied $b$-closed map.

The aim of this paper is to introduce pre generalized $b$-closed map and to continue the study of its relationship with various generalized closed maps. Throughout this paper $(X, \tau)$ and $(Y, \sigma)$ represent the non-empty topological spaces on which no separation axioms are assumed, unless otherwise mentioned.
2. Preliminaries

In this section, we referred some of the closed set definitions which was already defined by various authors.

**Definition 2.1.** [12] Let a subset $A$ of a topological space $(X, \tau)$, is called a pre-open set if $A \subseteq int(cl(A))$.

**Definition 2.2.** [7] Let a subset $A$ of a topological space $(X, \tau)$, is called a semi-open set if $A \subseteq cl(int(A))$.

**Definition 2.3.** [15] Let a subset $A$ of a topological space $(X, \tau)$, is called an $\alpha$-open set if $A \subseteq int(cl(int(A)))$.

**Definition 2.4.** [3] Let a subset $A$ of a topological space $(X, \tau)$, is called a $b$-open set if $A \subseteq cl(int(A)) \cup int(cl(A))$.

**Definition 2.5.** [6] Let a subset $A$ of a topological space $(X, \tau)$, is called a generalized closed set (briefly $g$-closed) if $cl(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is open in $X$.

**Definition 2.6.** [8] Let a subset $A$ of a topological space $(X, \tau)$, is called a generalized $\alpha$ closed set (briefly $g\alpha$-closed) if $\alpha cl(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is $\alpha$ open in $X$.

**Definition 2.7.** [2] Let a subset $A$ of a topological space $(X, \tau)$, is called a generalized $b$-closed set (briefly $gb$-closed) if $bcl(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is open in $X$.

**Definition 2.8.** [9] Let a subset $A$ of a topological space $(X, \tau)$, is called a generalized $\alpha^*$-closed set (briefly $ga^*$-closed) if $\alpha cl(A) \subseteq intU$ whenever $A \subseteq U$ and $U$ is $\alpha$ open in $X$.

**Definition 2.9.** [17] Let a subset $A$ of a topological space $(X, \tau)$, is called a pre-generalized closed set (briefly $pg$-closed) if $pcl(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is pre-open in $X$.

**Definition 2.10.** [4] Let a subset $A$ of a topological space $(X, \tau)$, is called a semi generalized closed set (briefly $sg$-closed) if $scl(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is semi open in $X$.

**Definition 2.11.** [18] Let a subset $A$ of a topological space $(X, \tau)$, is called a generalized $\alpha b$-closed set (briefly $gab$-closed) if $bcl(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is $\alpha$ open in $X$. 
Definition 2.12. [10] Let a subset $A$ of a topological space $(X, \tau)$, is called a regular generalized $b$- closed set (briefly $rgb$- closed) if $bc(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is regular open in $X$.

Definition 2.13. [13] Let a subset $A$ of a topological space $(X, \tau)$, is called pre generalized $b$- closed set (briefly $pgb$- closed set) if $bc(A) \subseteq U$ whenever $A \subseteq U$ and $U$ is pre open in $X$.

3. On Pre Generalized $b$-Closed Map

In this section, we introduce pre generalized $b$- closed map ($pgb$- closed map) in topological spaces by using the notions of $pgb$- closed sets and study some of their properties.

Definition 3.1. Let $X$ and $Y$ be two topological spaces. A map $f : (X, \tau) \to (Y, \delta)$ is called pre generalized star $b$- closed (briefly, $pgb$- closed map) if the image of every closed set in $X$ is $pgb$-closed in $Y$.

Theorem 3.2. Every closed map is $pgb$- closed but not conversely.

Proof. Let $f : (X, \tau) \to (Y, \delta)$ is closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$ - closed in $Y$. Then $f$ is $pgb$ - closed. \qed

The converse of above theorem need not be true as seen from the following example.

Example 3.3. Consider $X = Y = \{a, b, c\}$, $\tau = \{X, \phi, \{a, c\}\}$ and $\sigma = \{Y, \phi, \{b\}, \{b, c\}\}$. Let $f : (X, \tau) \to (Y, \sigma)$ be defined by $f(a) = b, f(b) = c, f(c) = a$. The map is $pgb$ - closed but not closed as the image of and $\{b\}$ in $X$ is $\{c\}$ is not closed in $Y$.

Theorem 3.4. Every $b$ - closed map is $pgb$- closed set but not conversely.

Proof. Let $f : (X, \tau) \to (Y, \sigma)$ is $b$ - closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$ - closed in $Y$. Then $f$ is $pgb$ - closed. \qed

The converse of above theorem need not be true as seen from the following example.

Example 3.5. Consider $X = Y = \{a, b, c\}$, $\tau = \{X, \phi, \{c\}\}$ and $\sigma = \{Y, \phi, \{a\}, \{a, b\}, \{b, c\}\}$. Let $f : (X, \tau) \to (Y, \sigma)$ be defined by $f(a) = c, f(b) = a, f(c) = b$. The map is $pgb$ - closed but not $b$ - closed as the image of and $\{a, b\}$ in $X$ is $\{a, c\}$ is not $b$ - closed in $Y$. 

Theorem 3.6. Every $g\alpha$ - closed map is $pgb$ - closed but not conversely.

Proof. Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be $g\alpha$-closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$ - closed in $Y$. Then $f$ is $pgb$ - closed. \qed

The converse of above theorem need not be true as seen from the following example.

Example 3.7. Consider $X = Y = \{a, b, c\}$, $\tau = \{X, \phi, \{a\}, \{a, b\}\}$ and $\sigma = \{Y, \phi, \{a\}, \{c\}, \{a, c\}\}$. Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be defined by $f(a) = a, f(b) = c, f(c) = b$. The map is $pgb$ - closed but not $g\alpha$-closed as the image of $\{b, c\}$ in $X$ is $\{a, b\}$ is not $g\alpha$-closed in $Y$.

Theorem 3.8. Every $g\alpha^\ast$ - closed map is $pgb$ - closed but not conversely.

Proof. Let $f : (X, \tau) \rightarrow (Y, \delta)$ be $g\alpha^\ast$ - closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$ - closed in $Y$. Then $f$ is $pgb$ - closed. \qed

The converse of above theorem need not be true as seen from the following example.

Example 3.9. Consider $X = Y = \{a, b, c\}$, $\tau = \{X, \phi, \{b, c\}\}$ and $\sigma = \{Y, \phi, \{a\}, \{b\}, \{a, b\}\}$. Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be defined by $f(a) = b, f(b) = c, f(c) = a$. The map is $pgb$ - closed but not $g\alpha^\ast$ - closed as the image of $\{a\}$ in $X$ is $\{b\}$ is not $g\alpha^\ast$ - closed in $Y$.

Theorem 3.10. Every $g$ - closed map is $pgb$ - closed but not conversely.

Proof. Let $f : (X, \tau) \rightarrow (Y, \delta)$ $g$ - closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$ - closed in $Y$. Then $f$ is $pgb$ - closed. \qed

The converse of above theorem need not be true as seen from the following example.

Example 3.11. Consider $X = Y = \{a, b, c\}, \tau = \{X, \phi, \{a, b\}\}$ and $\sigma = \{Y, \phi, \{b\}, \{c\}, \{b, c\}\}$. Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be defined by $f(a) = c, f(b) = a, f(c) = b$. The map is $pgb$ - closed but not $g$-closed as the image of $\{c\}$ in $X$ is $\{b\}$ is not $g$-closed in $Y$.

Theorem 3.12. Every $g\alpha b$ - closed map is $pgb$ - closed but not conversely.

Proof. Let $f : (X, \tau) \rightarrow (Y, \sigma)$ be $g\alpha b$ - closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$ - closed in $Y$. Then $f$ is $pgb$ - closed. \qed
The converse of above theorem need not be true as seen from the following example.

**Example 3.13.** Consider $X = Y = \{a, b, c\}, \tau = \{X, \phi, \{a\}, \{a, c\}\}$ and $\sigma = \{Y, \phi, \{a\}, \{c\}, \{a, c\}, \{b, c\}\}$. Let $f : (X, \tau) \to (Y, \sigma)$ be defined by $f(a) = a, f(b) = c, f(c) = b$. The map is $pgb$-closed but not $gab$-closed as the image of and $\{b, c\}$ in $X$ is $\{b, c\}$ is not $gab$-closed in $Y$.

**Theorem 3.14.** Every $rgb$-closed map is $pgb$-closed but not conversely.

**Proof.** Let $f : (X, \tau) \to (Y, \delta)$ be $rgb$ closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$-closed in $Y$. Then $f$ is $pgb$-closed. $\square$

The converse of above theorem need not be true as seen from the following example.

**Example 3.15.** Consider $X = Y = \{a, b, c\}, \tau = \{X, \phi, \{b\}, \{c\}, \{b, c\}\}$ and $\sigma = \{Y, \phi, \{a\}, \{b\}, \{c\}\}$. Let $f : (X, \tau) \to (Y, \sigma)$ be defined by $f(a) = b, f(b) = c, f(c) = a$. The map is $pgb$-closed but not $rgb$-closed as the image of $\{a\}$ in $X$ is $\{b\}$ is not $rgb$-closed in $Y$.

**Theorem 3.16.** Every $pgb$-closed map is $pgb$-closed but not conversely.

**Proof.** Let $f : (X, \tau) \to (Y, \delta)$ be $pgb$-closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $gb$-closed in $Y$. Then $f$ is $gb$-closed. $\square$

The converse of above theorem need not be true as seen from the following example.

**Example 3.17.** Consider $X = Y = \{a, b, c\}, \tau = \{X, \phi, \{a, b\}\}$ and $\sigma = \{Y, \phi, \{a\}\}$. Let $f : (X, \tau) \to (Y, \sigma)$ be defined by $f(a) = b, f(b) = c, f(c) = a$. The map is $pg$-closed but not $pgb$-closed as the image of $\{a, c\}$ in $X$ is $\{a, b\}$ is not $pgb$-closed in $Y$.

**Theorem 3.18.** Every $sg$-closed map is $pgb$-closed but not conversely.

**Proof.** Let $f : (X, \tau) \to (Y, \delta)$ be $sg$-closed map and $V$ be an closed set in $X$ then $f(V)$ is closed in $Y$. Hence $pgb$-closed in $Y$. Then $f$ is $pgb$-closed. $\square$

The converse of above theorem need not be true as seen from the following example.

**Example 3.19.** Consider $X = Y = \{a, b, c\}, \tau = \{X, \phi, \{a, b\}\}$ and $\sigma = \{Y, \phi, \{a, c\}\}$. Let $f : (X, \tau) \to (Y, \sigma)$ be defined by $f(a) = c, f(b) = b, f(c) = a$. The map is $pgb$-closed but not $sg$-closed as the image of $\{c\}$ in $X$ is $\{a\}$ is not $sg$-closed in $Y$. 
**Theorem 3.20.** A map \( f : (X, \tau) \to (Y, \sigma) \) is continuous and pgb - closed set \( A \) is pgb - closed set of \( X \) then \( f(A) \) is pgb closed in \( Y \).

**Proof.** Let \( f(A) \subseteq U \) where \( U \) is regular open set in \( Y \). Since \( f \) is continuous, \( f^{-1}(U) \) is open set containing \( A \). Hence \( bcl(A) \subseteq f^{-1}(U) \) as \( A \) is pgb - closed. Since \( f \) is pgb - closed \( f(bcl(A)) \subseteq U \) is pgb closed set \( \Rightarrow bcl(f(bcl(A))) \subseteq U \), Hence \( bcl(A) \subseteq U \). So that \( f(A) \) is pgb - closed set in \( Y \).

**Theorem 3.21.** If a map \( f : (X, \tau) \to (Y, \sigma) \) is continuous and closed set and \( A \) is pgb - closed then \( f(A) \) is pgb - closed in \( Y \).

**Proof.** Let \( F \) be a closed set of \( A \) then \( F \) is pgb - closed set. By theorem 3.20 \( f(A) \) is pgb - closed. Hence \( f(A)(F) = f(F) \) is pgb - closed set of \( Y \). Here \( f_A \) is pgb - closed and also continuous.

**Theorem 3.22.** If \( f : (X, \tau) \to (Y, \sigma) \) is closed map and \( g : (Y, \sigma) \to (Z, \eta) \) is pgb - closed map , then the composition \( g \cdot f : (X, \tau) \to (Z, \eta) \) is pgb - closed map.

**Proof.** Let \( F \) be any closed set in \( (X, \tau) \). Since \( f \) is closed map, \( f(F) \) is closed set in \( (Y, \sigma) \). Since \( g \) is pgb - closed map, \( g(f(F)) \) is pgb - closed set in \( (Z, \eta) \). That is \( g \cdot f(F) = g(f(F)) \) is pgb closed. Hence \( g \cdot f \) is pgb closed map.

**Remark 3.23.** If \( f : (X, \tau) \to (Y, \sigma) \) is pgb - closed map and \( g : (Y, \sigma) \to (Z, \eta) \) is closed map, then the composition need not pgb - closed map .

**Theorem 3.24.** A map \( f : (X, \tau) \to (Y, \sigma) \) is pgb - closed if and only if for each subset \( S \) of \( (Y, \sigma) \) and each open set \( U \) containing \( f^{-1}(S) \subseteq U \), there is a pgb - open set \( V \) of \( (Y, \sigma) \) such that \( S \subseteq V \) and \( f^{-1}(V) \subseteq U \).

**Proof.** Suppose \( f \) is pgb - closed. Let \( S \subseteq Y \) and \( U \) be an open set of \( (X, \tau) \) such that \( f^{-1}(S) \subseteq U \). Now \( X - U \) is closed set in \( (X, \tau) \). Since \( f \) is pgb - closed, \( f(X - U) \) is pgb - closed set in \( (Y, \sigma) \). Therefore \( V = Y f(X - U) \) is an pgb - open set in \( (Y, \sigma) \). Now \( f^{-1}(S) \subseteq U \) implies \( S \subseteq V \) and \( f^{-1}(V) = X - f^{-1}(f(X - U)) \subseteq X - (X - V) = U \). (ie) \( f^{-1}(V) \subseteq U \).

Conversely,

Let \( F \) be a closed set of \( (X, \tau) \). Then \( f^{-1}(f(F^c)) \subseteq F^c \) and \( F^c \) is an open in \( (X, \tau) \). By hypothesis, there exist a pgb - open set \( V \) in \( (Y, \sigma) \) such that \( f(F^c) \subseteq V \) and \( f^{-1}(V) \subseteq F^c \Rightarrow F \subseteq f^{-1}(V)^c \). Hence \( V^c \subseteq f(F) \subseteq
Theorem 3.25. If \( f : X_1 \times X_2 \rightarrow Y_1 \times Y_2 \) is defined as \( f(x_1, x_2) = (f_1(x_1), f_2(x_2)) \), then \( f : X_1 \times X_2 \rightarrow Y_1 \times Y_2 \) is \( pgb \)-closed map.

Proof. Let \( U_1 \times U_2 \subset X_1 \times X_2 \) where \( U_i \in pgbcl(X_i) \), for \( i = 1, 2 \). Then \( f(U_1 \times U_2) = f_1(U_1) \times f_2(U_2) \in pgbcl(X_1 \times Y_2) \). Hence \( f \) is \( pgb \)-closed set.

Theorem 3.26. Let \( h : X \rightarrow X_1 \times X_2 \) be \( pgb \)-closed map and \( f_i : X \times X_i \) be define as \( h(x) = (x_1, x_2) \) and \( f_i(x) = x_i \), then \( f_i : X \times X_i \) is \( pgb \)-closed map for \( i = 1, 2 \).

Proof. Let \( U_1 \times U_2 \in X_1 \times X_2 \), then \( f_1(U_1) = h_1(U_1 \times X_2) \in pgbcl(X) \), there fore \( f_1 \) is \( pgb \)-closed. Similarly we have \( f_2 \) is \( pgb \)-closed. Thus \( f_i \) is \( pgb \)-closed map for \( i = 1, 2 \).

Theorem 3.27. For any bijection map \( f : (X, \tau) \rightarrow (Y, \sigma) \), the following statements are equivalent:

(i) \( f^{-1} : (Y, \sigma) \rightarrow (X, \tau) \) is \( pgb \)-continuous.

(ii) \( f \) is \( pgb \)-open map.

(iii) \( f \) is \( pgb \)-closed map.

Proof. (i)\( \Rightarrow \) (ii) Let \( U \) be an open set of \( (X, \tau) \). By assumption, \( (f^{-1})^{-1}(U) = f(U) \) is \( pgb \)-open in \( (Y, \sigma) \) and so \( f \) is \( pgb \)-open.

(ii)\( \Rightarrow \) (iii) Let \( F \) be a closed set of \( (X, \tau) \). Then \( F^c \) is open set in \( (X, \tau) \). By assumption \( f(F^c) \) is \( pgb \)-open in \( (Y, \sigma) \). Therefore \( f(F^c) = f(F)^c \) is \( pgb \)-open in \( (Y, \sigma) \). That is \( f(F) \) is \( pgb \)-closed in \( (Y, \sigma) \). Hence \( f \) is \( pgb \)-closed.

(iii)\( \Rightarrow \) (i) Let \( F \) be a closed set of \( (X, \tau) \). By assumption, \( f(F) \) is \( pgb \)-closed in \( (Y, \sigma) \). But \( f(F) = (f^{-1})^{-1}(F) \Rightarrow (f^{-1}) \) is continuous.

\( \square \)
4. On Pre Generalized \( b \)-Open Map

In this section, we introduce pre generalized \( b \)-open map (briefly \( pgb \)-open) in topological spaces by using the notions of \( pgb \)-open sets and study some of their properties.

**Definition 4.1.** Let \( X \) and \( Y \) be two topological spaces. A map \( f : (X, \tau) \rightarrow (Y, \delta) \) is called pre generalized \( b \)-open (briefly, \( pgb \)-open) if the image of every open set in \( X \) is \( pgb \)-open in \( Y \).

**Theorem 4.2.** Every open map is \( pgb \)-open but not conversely.

**Proof.** Let \( f : (X, \tau) \rightarrow (Y, \delta) \) be open map and \( V \) be an open set in \( X \) then \( f(V) \) is open in \( Y \). Hence \( pgb \)-open in \( Y \). Then \( f \) is \( pgb \)-open. \( \square \)

The converse of above theorem need not be true as seen from the following example.

**Example 4.3.** Consider \( X = Y = \{a, b, c\}, \tau = \{X, \emptyset, \{c\}\} \) and \( \sigma = \{Y, \emptyset, \{b\}, \{b, c\}\} \). Let \( f : (X, \tau) \rightarrow (Y, \sigma) \) be defined by \( f(a) = b, f(b) = a, f(c) = c \). The map is \( pgb \)-open but not open as the image of and \( \{a, b\} \) in \( X \) is \( \{a, b\} \) is not open in \( Y \).

**Theorem 4.4.** A map \( f : (X, \tau) \rightarrow (Y, \sigma) \) is \( pgb \)-closed set if and only if for each subset \( S \) of \( Y \) and for each open set \( U \) containing \( f^{-1}(S) \subseteq U \) there is a \( pgb \)-open set \( V \) of \( Y \) such that \( S \subseteq U \) and \( f^{-1}(V) \subseteq U \).

**Proof.** Suppose \( f \) is \( pgb \)-closed set. Let \( S \subseteq Y \) and \( U \) be an open set of \( (X, \tau) \) such that \( f^{-1}(S) \subseteq U \). Now \( X - U \) is closed set in \( (X, \tau) \). Since \( f \) is \( pgb \)-closed, \( f(X - U) \) is \( pgb \) closed set in \( (Y, \sigma) \). Then \( V = Y - f(X - U) \) is \( pgb \)-open set in \( (Y, \sigma) \). There fore \( f^{-1}(S) \subset U \) implies \( S \subset V \) and \( f^{-1}(V) = X - f^{-1}(f(X - U)) \subset X - (X - V) = U \). (ie) \( f^{-1}(V) \subset U \).

Conversely,

Let \( F \) be a closed set of \( (X, \tau) \). Then \( f^{-1}(F^c) \subset F^c \) and \( F^c \) is an open in \( (X, \tau) \). By hypothesis, there exists a \( pgb \)-open set \( V \) in \( (Y, \sigma) \) such that \( f(F^c) \subset V \) and \( f^{-1}(V) \subset F^c \Rightarrow F \subset (f^{-1}(V))^c \). Hence \( V^c \subset f(F) \subset f(((f^{-1}(V))^c)^c) \subset V^c \Rightarrow f(V) \subset V^c \). Since \( V^c \) \( pgb \)-closed, \( f(F) \) is \( pgb \)-closed. (ie) \( f(F) \) is \( pgb \)-closed in \( (Y, \sigma) \) and there fore \( f \) is \( pgb \)-closed. \( \square \)

**Theorem 4.5.** For any bijection map \( f : (X, \tau) \rightarrow (Y, \sigma) \), the following statements are equivalent.

(i) \( f^{-1} : (X, \tau) \rightarrow (Y, \sigma) \) is \( pgb \)-continuous.
(ii) \( f \) is \( pgb \) open map.

(iii) \( f \) is \( pgb \)-closed map.

Proof. (i)\( \Rightarrow \) (ii) Let \( U \) be an open set of \( (X, \tau) \). By assumption \( (f^{-1})^{-1}(U) = f(U) \) is \( pgb \)-open in \( (Y, \sigma) \). Therefore \( f \) is \( pgb \)-open map.

(ii)\( \Rightarrow \) (iii) Let \( F \) be a closed set of \( (X, \tau) \). Then \( F^c \) is open in \( (X, \tau) \). By assumption, \( f(F^c) \) is \( pgb \)-open in \( (Y, \sigma) \). Therefore \( f(F) \) is \( pgb \)-closed in \( (Y, \sigma) \). Hence \( f \) is \( pgb \)-closed.

(iii)\( \Rightarrow \) (i) Let \( F \) be a closed set of \( (X, \tau) \). By assumption \( f(F) \) is \( pgb \)-closed in \( (Y, \sigma) \). But \( f(F) = (f^{-1})^{-1}(F) \). Hence \( f^{-1} : (X, \tau) \to (Y, \sigma) \) is \( pgb \)-continuous. \( \square \)

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