

Research Article



Comparative Study of Crop Water Productivity at Farm Level under Public and Civil Canal Irrigation Systems in Peshawar, Pakistan

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Abstract | Agriculture consumes more water than any other human activity. In Pakistan, the contribution of irrigated agriculture is more than 90%, thus the sustainable water supply to meet the food and fibre demand of the ever increasing population is a big challenge. Increase in crop water productivity (CWP) is one of the most important options for sustainable use of water resources in semi-arid environment. A field study was conducted during *Rabi* 2010-11 and *Kharif* 2011 crop seasons to compare the CWP of main crops (wheat, sugarcane, maize and tomato) under public and civil canal irrigation systems in Peshawar Valley. For this purpose, 18 farms were selected under public canal system and 13 under civil canal systems. Results revealed that average CWP of wheat, maize, sugarcane and tomato was 0.96, 1.11, 3.31, 3.61 kg m⁻³ under public and 0.90, 0.77, 2.36, 2.98 kg m⁻³, under civil system, respectively. In public canal system, the average CWP of the selected crops was 7, 40, 44 and 21% higher than civil canal system, respectively. Low CWP in civil canal system was mainly attributed to over irrigation (because of high water allowance). Quantitative analysis of the yield per unit volume of water applied was carried out using dummy-regression model. The difference in means for maize, sugarcane and tomato crop was found highly significant while in case of wheat it was non-significant. This study concludes that the public system remained more productive with high CWP at farm level for all the major crops. However, there is a great potential for increasing CWP under civil system by rationalizing the water allowance.

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Introduction

Although, the issue of water scarcity is rarely talked about in Pakistan's politics, but it yet constitutes one of the biggest challenges to the country's survival with a projected population of 263 million by the year 2050. Water demand in the country for domestic, industry and environment is rapidly in-

creasing resulting in stress on sustainable water supply to the irrigated agriculture, which contributes more than 90% of the total crop production. Annual per capita water availability in the country is < 1000 m³, thus placing it in the list of water scarce countries (Raheel, 2013).

Pakistan is blessed with many natural gifts and one

of them is the surface irrigation system. Khyber Pakhtunkhwa (KP) has comparatively greater potential to provide more water per unit area than any other systems in the country. Better rainfall with enough water has led the development of extensive irrigation systems in the province. Out of two major irrigation systems in the province, the first is “public canal systems” where the principal management is the responsibility of Irrigation Department with farmers playing a subsidiary role at tertiary level. Second type is “civil canal systems” which is operated and maintained by the farmers with the government providing periodic technical or logistic support. Civil system in the study area is a combination of inundation canals taking-off from Kabul and Indus rivers dug way back in the Mughal’s era. The two systems commanding agriculture lands with similar cropping conditions in Peshawar valley have different water allowance.

Crop water productivity (CWP) is a one of the indicator to compare the performance two systems with different water allowance and more or less same out put. CWP is defined as the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water, or available water (Brauman, 2013). According to Liu et al. (2007) and Igbadun et al. (2006), CWP is a useful indicator for determining the impact of irrigation scheduling decisions. Deficit irrigation is a key strategy for increasing water productivity in water scarce areas. Increase in CWP is one of the pathway to get more crop per drop in arid and semiarid regions. Moreover, improvements in farm management practices, crop technology, timeliness of input use, and efficient use of water result in to enhancement of CWP (Dehghanisanij et al., 2008). A study was conducted in winter (*Rabi*) and summer (*Kharif*) cropping season of 2010-2011 with the objective to compare the CWP of public and civil canal systems.

Materials and Methods

Description of study area

The research area located in district Peshawar basin (>5500 km²) situated at the southern margin of the Himalaya with Federally Administered Tribal Areas (FATA), the Khyber Agency in the West, Mohmand Agency in North-West, Frontier Region (Semi-Tribal regions) and Kohat district in the South. The two settled districts of Charsadda and Nowshera are situated to its North and North-East, respectively. Peshawar

lies between 33° 44' and 34° 15' North latitude and 71° 22' and 71° 42' East longitude. It consists of fine alluvial deposits with tracts of a rich, light and porous soil, composed of a pretty even mixture of clay and sand. Peshawar lies 358 meters above mean sea level with semi-arid climate having very hot summers (May to September) and mild winters (November to March). Unlike other parts of the province, Peshawar is not a monsoon region but still rainfall is received both in winter as well as summer (Nasreen, 2006).

The basin is irrigated by the Kabul River and its tributaries originating from *Unai Pass* in the *Paghman Mountains* near Kabul and reaches Warsak Dam, Peshawar. At the downstream end of Warsak Dam, the Moghul Emperor, Aurangzeb Alamgir, constructed inundation canals in late 1600s known as the Kabul River Canal System (KRC) as the first major system of the province. KP Irrigation department is the only institution either completely or partially regulating these irrigation systems in the province. Like other systems of the province, KRC is also a rigid supply-based system with a mixture of public as well as civil canals. In Public system, the the canals are operated/regulated completely by the Irrigation department. Civil canal system supplying water to 30% of the total irrigated land in the province is managed by the community and exempted from *Abiana* (water charges). In the British era, written and documented rules were introduced for operation and maintenance of this system called “*Kuliat and Rawajat-e-Aabpashi*” which are still used effectively. In Peshawar valley, Kabul River Canal (Public) and Joe-Sheikh Canal (Civil) are the two major canals (Table 1). Wheat-sugarcane in winter (*Rabi*) season and maize-sugarcane with tomato in summer (*Kharif*) season is the cropping pattern under both the systems despite enough water allowance. In order to compare the CWP of two systems, major crops in the command area i.e. wheat, maize, sugarcane and tomato were selected for which a multi-stage sampling scheme was adopted. KRC (public) and JSC (civil) providing a good chance of carrying out such a comparative study, were selected (Figure 1). Keeping the size of the above canals in view, three watercourses were selected at head, middle and tail regions of each system. Two farms (farmer’s fields) each at head, middle and tail regions were also selected randomly, except civil canal where it was not possible to select farms at the head region due to small land holdings. Hence, total 31 farms were selected on both the systems.

Table 1: Details of selected canals

Canal	Type	Length (km)	Minors (Nos)	Outlets (Nos)	CCA (ha)	Designed discharge (m ³ s ⁻¹)	Water allowance (Ls ⁻¹ ha ⁻¹)
KRC	Public	61	4	160	16,715	12.74	0.76
JSC	Civil	43	2	124	10,112	9.91	0.98

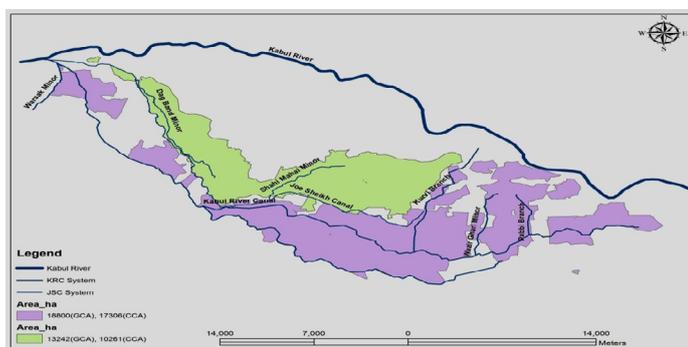


Figure 1: Digitized map of KRC & JSC

Crop water productivity

CWP of selected crops was determined in physical terms for both public and civil canal systems using following equation (Igbadun et al., 2006):

$$CWP = Yield \div SWA \dots \dots \dots (1)$$

Where

- CWP = Crop water productivity ((kg m⁻³)
- Yield = Crop yield (kg)
- SWA = Seasonal water applied (m³)

Yield

Crop produced in each of the selected field was actually measured upon harvesting. For this purpose, steel rings (1-2 m²) prepared from the local market were used. Three samples from each selected field of all the crops were collected and yield was measured by weighing each sample on electronic scale. In case of wheat and maize, the grain and straw weight was measured separately.

Seasonal water applied (SWA)

SWA to the selected crops during the whole growing season was measured. Irrigation water supply (in each turn) to a field was measured through cut-throat flume. Rainfall data for the study period was obtained from Agricultural Research Station (ARS), Tarnab, Peshawar, effective rainfall (P_{eff}) was calculated by dependable rainfall method using Cropwat program. Accordingly, SWA to each crop was calculated using following expression (Igbadun et al., 2006):

$$SWA = (Q \times T \times N) + P_{eff} \dots (2)$$

where

- SWA= Seasonal water applied (m³)
- Q = Discharge measured at farm level through a flume (m³s⁻¹)
- T = Time per irrigation (s)
- N = Total Number of irrigations
- P_{eff} = Effective rainfall (m³)

In order to test the significance of difference in mean CWP of two irrigation systems, dummy variables regression model was used through a computer software EVIEWS6 (Gujarati, 2003).

$$CWP_i = \beta_0 + \beta_1 D_i + v_i \dots \dots (3)$$

Where

- CWP_i = Crop water productivity (kg m⁻³) of ith irrigation system
- β₀ and β₁= Parameters (β₀ is benchmark category and shows CWP of civil system).
- D_i = Dummy variable having the value of “1” if belongs to public irrigation system and 0 otherwise.
- v_i = Error term

Results and Discussion

The CWP values of wheat ranged from 0.83-1.06 kg m⁻³ under public and 0.83-0.96 kg m⁻³ under civil system (Table 2). Mean CWP of wheat under public system was 7% higher than civil system. Mean CWP of wheat under civil and public system was 0.90 kg m⁻³ and 0.96 kg m⁻³, respectively. Regression results show that the difference in CWP of the two systems was not significant. Dehghanisanij et al., (2009) found CWP values of 0.50-1.80 kg m⁻³ for wheat crop and recommended 1.50 kg m⁻³ as an optimum level. Afshar (2004), Jehangir et al. (2007), Montazar and Kosri (2007), Ashraf et al. (2010), Cai et al. (2010) and Karrou (2012) observed CWP of 1.50, 1.48, 1.62, 0.73, 0.94 and 1.53 kg m⁻³, respectively. Singh (2005), Igbadun et al. (2006), Qureshi (2009) and Aiken et al. (2013) reported the CWP range of 1.22-1.56 kg m⁻³, 0.40-0.55 kg m⁻³, 0.45-0.85 kg m⁻³ and 0.28-0.62 kg m⁻³, respectively. CWP of wheat in the present study was found slightly on lower side in both the systems; however, it was within the acceptable limits. There is

Table 2: *Crop water productivity of wheat*

Farm No.	Public Canal System			Civil Canal System		
	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)
1	1482	2757	0.93	1638	3514	0.86
2	1424	2569	0.90	2151	3555	0.83
3	1025	3115	1.06	2296	3459	0.90
4	627	3069	0.98	2337	3598	0.92
5	652	3130	0.96	2486	3447	0.90
6	937	2738	0.88	1614	3629	0.90
7	1348	2481	0.83	1548	3693	0.95
8	1113	2520	0.91	2397	3811	0.95
9	781	2738	0.88	2186	3778	0.95
10	630	3135	1.00	2170	3801	0.88
11	909	2727	0.90	2124	3716	0.96
12	638	3230	1.01	1998	3493	0.87
13	1075	3128	1.02	1748	3609	0.83
14	893	3020	1.01	-	-	-
15	967	3330	1.03	-	-	-
16	950	2930	0.93	-	-	-
17	893	3097	1.04	-	-	-
18	624	3069	0.98	-	-	-
Mean	943	2932	0.96	2053	3623	0.90
C.V. (%)	29	9	7	15	4	5

Table 3: *Crop water productivity of maize*

Farm No.	Public Canal System			Civil Canal System		
	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)
1	1797	1987	1.11	2790	2072	0.74
2	1967	2023	1.03	3500	2455	0.70
3	1316	1517	1.15	3316	2479	0.75
4	1157	1309	1.13	2465	2126	0.86
5	1130	1177	1.04	3019	2050	0.68
6	1487	1542	1.04	1991	1725	0.87
7	1785	1979	1.11	2387	1620	0.68
8	1370	1502	1.10	3162	2547	0.81
9	1112	1241	1.12	3231	2442	0.76
10	1101	1349	1.23	2523	1647	0.65
11	1232	1442	1.17	3334	2916	0.87
12	731	847	1.16	2820	2588	0.92
13	1585	1746	1.10	3395	2499	0.74
14	1210	1289	1.07	-	-	-
15	1260	1343	1.07	-	-	-
16	979	1047	1.07	-	-	-
17	1128	1286	1.14	-	-	-
18	740	839	1.13	-	-	-
Mean	1283	4299	1.11	2918	4166	0.77
C.V. (%)	26	4	5	16	2	11

still a huge gap between the actual and potential CWP.

CWP of maize ranged from 1.03-1.23 kg m⁻³ under public systems and 0.65-0.92 kg m⁻³ in civil system (Table 3). In public system, CWP of maize was 44% higher than the civil system. Mean CWP of maize under civil and public system was 0.77 kg m⁻³ and 1.11 kg m⁻³. Regression results showed significant difference in CWP of maize between the two systems. Igbadun et al. (2006) and Karrou (2012) reported CWP of 1.20-1.50 kg m⁻³ and 1.53-1.99 kg m⁻³ for maize. Dehghanisanij et al. (2009) reported CWP range of 0.30-2.30 kg m⁻³ and recommended optimum CWP value of 1.70 kg m⁻³ for maize crop. Afshar (2004), Montazar and Kosri (2007), Ashraf et al. (2010) determined the CWP of 1.70, 1.30 and 2.01 kg m⁻³, respectively. In the present study, CWP figures under public system were within the acceptable range while in case of civil system, it was quite low mainly due to excessive application of water and low crop yield.

For sugarcane, the CWP varied from 3.13-3.50 kg m⁻³ in public system and 2.22-2.50 kg m⁻³ under civil system (Table 4). In case of sugarcane, the CWP of public system was recorded 40% higher than the civil system. Mean CWP under civil and public system was 2.36 kg m⁻³ and 3.31 kg m⁻³. Regression results showed significant difference in CWP of sugarcane between the two systems. Singh (2005) obtained mean CWP of 7.1 kg m⁻³ for sugarcane while Ashraf et al. (2010) reported CWP value of 2.01 kg m⁻³. In

the present study, low crop yield and excessive water application were the major factors for low CWP values in civil canal system.

CWP of tomato ranged from 3.10-3.91 kg m⁻³ under public system and 2.75-3.53 kg m⁻³ in civil system (Table 5). Average CWP of civil and public system was 2.98 kg m⁻³ and 3.61 kg m⁻³, respectively. The average CWP of public system was found 21% higher than the civil system. Regression results showed significant difference in CWP of sugarcane between the two the systems. Rashidi (2008) reported CWP of 2.58-11.88 kg m⁻³, while Montazar and Kosari (2007) reported CWP of 6.77 kg m⁻³ for tomato crop. The findings of this study are in agreement with the previous studies.

SWA-Yield response

Overall 32% more water was applied to wheat crop under civil system as compared to public system. Maximum yield was obtained at 410-450 mm water depth (Figure 2) and further application resulted in yield decrease. However, the average SWA in both the systems was found less than the optimal range. Shahnaz et al. (2013) reported relatively higher yields of wheat under public system. Khan et al. (2004) reported a significant increase in wheat yield by applying 3rd irrigation during the month of March. In the present study, no irrigation was applied in March due to canal closure and the farmers had to rely on rainfall.

Similarly, maize crop was irrigated 3-4 times in the

Table 4: Crop water productivity of sugarcane

Farm No.	Public Canal System			Civil Canal System		
	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)
1	-	-	-	6685	50310	2.26
2	-	-	-	8228	50007	2.43
3	-	-	-	4526	50162	2.22
4	-	-	-	3990	49923	2.50
7	4422	47883	3.25	-	-	-
8	3915	49507	3.16	-	-	-
10	-	-	-	8577	50697	2.36
12	3172	49573	3.13	6051	49087	2.43
13	4384	49792	3.41	4325	50440	2.33
16	2799	48483	3.46	-	-	-
17	2819	49397	3.50	-	-	-
18	3065	49860	3.25	-	-	-
Mean	3511	49214	3.31	6054	50089	2.36
C.V. (%)	20	2	5	31	1	4

Table 5: Crop water productivity of tomato

Farm No.	Public Canal System			Civil Canal System		
	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)	SWA (m ³)	Yield (kg ha ⁻¹)	CWP (kg m ⁻³)
1	1446	17613	3.65	1272	18678	2.94
2	968	17767	3.67	637	17604	2.77
3	-	-	-	646	17757	2.75
5	-	-	-	2570	18524	2.88
6	1061	17926	3.38	2162	17593	2.85
7	-	-	-	664	17348	2.87
8	826	17236	3.76	607	17440	2.87
9	1163	16710	3.45	571	17417	3.05
10	438	17136	3.91	620	17459	2.82
11	842	16471	3.91	1058	17707	3.35
12	-	-	-	1003	17707	3.53
13	-	-	-	2328	18307	3.14
14	1779	17386	3.71	-	-	-
15	1076	16660	3.10	-	-	-
16	451	16156	3.59	-	-	-
Mean	1005	17106	3.61	1178	17795	2.98
C.V. (%)	41	3	7	63	3	8

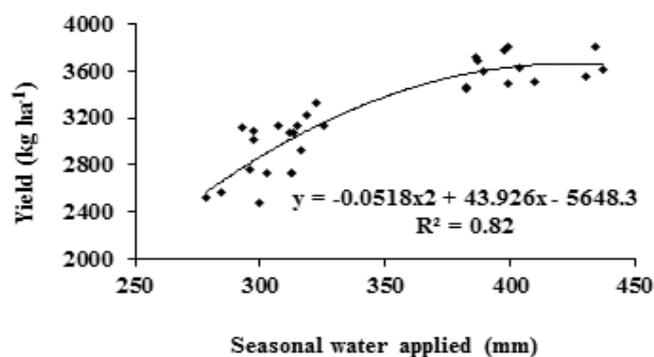


Figure 2: Yield-SWA relationship (wheat)

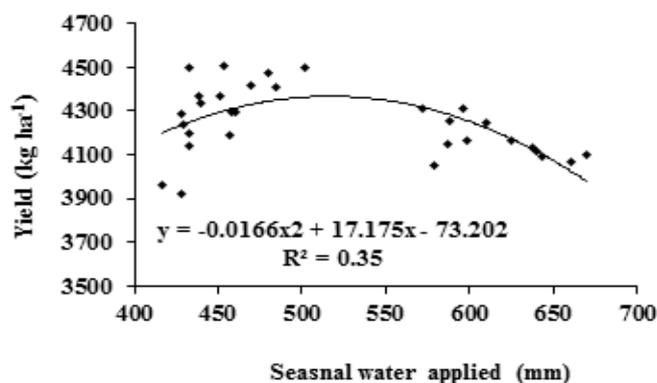


Figure 3: Yield-SWA relationship (maize)

whole season, including pre-sowing application and 47% more water was applied to maize crop under civil system as compared to public system. In public system, average depth of water applied was less while in civil system, it was higher than the optimal range

(Figure 3). A positive relationship was observed between the SWA and maize yield. Optimal range of 500-525 mm was observed as further application resulted in yield decrease.

Sugarcane was given 16-18 irrigations during the growing season where 43% more water was applied under civil system as compared to the public system. A linear relationship was observed between the yield and SWA (Figure 4). Irrigation at critical stage may have resulted in yield increase and thus CWP.

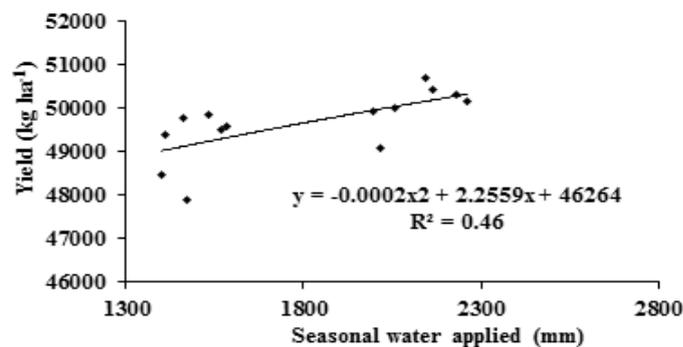


Figure 4: Yield-SWA relationship (sugarcane)

Tomato crop was irrigated 7-9 times in the growing season and the total volume of water applied under civil system was 26% higher than the public system. A positive relationship was observed between SWA and yield (Figure 5). In this study, optimal yield was found at

about 650 mm SWA. According to Jensen et al. (2010), total water need of tomato after transplantation is 400-600 mm thus supporting the results of this study.

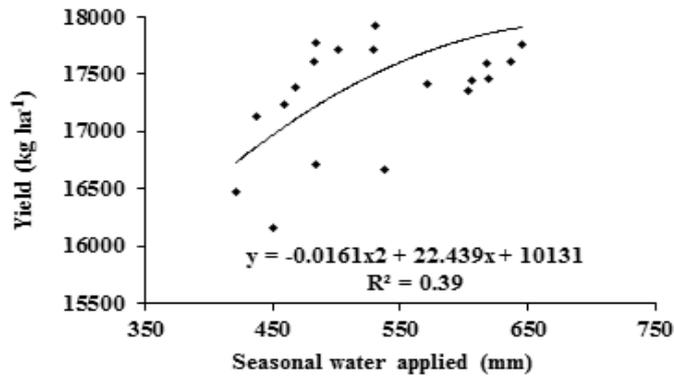


Figure 5: Yield-SWA relationship (tomato)

In the above relationships, it has been noticed that the curvilinear relationship is stronger for maize than other crops. Hence, farmers cultivating maize have to be more careful in using excessive water allowance under civil system. CWP can be improved by educating farmers on irrigation scheduling in order to avoid unwanted water stress on plants as well as excessive water application.

Lower CWP values of civil system are mainly due to over irrigation and relatively lower yields, hence, there is enough scope to enhance the CWP. According to Rasiuba (2007), the yield increases linearly with increase in water supply until it reaches a plateau with maximum yield and it is likely that further application of water can result in to decline in CWP. In order to sensitize the farmers regarding efficient use of available water, the productive applied water and yield relationship is a good concept. In case of excessive water, farmers can irrigate crop to the point where marginal CWP is equal to zero. Any further application of irrigation water beyond point of zero marginal CWP is a waste of water because no further yield increase can be expected but possibly a yield decrease. Abbas et al. (2006) observed that irrigation water is not applied according to the crop demand at different growth stages and an integrated management plan is required to regulate irrigation needs according to crop demand in both the systems. Moreover, there is critical water shortage during low discharge or canal closure period and wastage of water as surface runoff during forced irrigation turns and monsoon rains. As both the systems are supply based (rigid), the farmers have only two choices either to irrigate his field or miss his turn. Therefore, water is applied to the crop irrespective of its demand, resulting in to decline in to yield as well

as CWP.

Conclusions

In the present study, CWP of all the selected crops under civil canal system was found low as compared to public canal system. However, the difference in CWP of two systems was significant for maize, sugarcane and tomato and non-significant for wheat crop. This difference is mainly attributed to the amount of water applied under two systems. No significant increase in the crop yield was observed despite frequent water application under civil system. The farmers in most of the cases apply water within a regime where the yield response to irrigation is positive. In certain situations, farmers' water application regime corresponds to a regime where response of yield and CWP to the irrigation is either positive or negative. There is ample scope for improving CWP in irrigated agriculture through water regulation, however, the farmers will go for this option only if there is sufficient land that can be brought under command to utilize the saved water. This study concludes that the public system remained more productive with high CWP at farm level for all the major crops. However, there is a great potential for increasing CWP under civil system by rationalizing the water allowance.

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Authors Contribution

The concept and design of the research were developed by Rabnawaz with the help and guidance of following Supervisory Committee members: Muhammad Jamal Khan (WM), Tahir Sarwar and Muhammad Jamal Khan (SES). Rabnawaz conducted the trials, collected and analyzed all primary as well as secondary data and prepared the first draft of manuscript under the supervision of above-mentioned members. The draft manuscript was studied and amended accordingly by all the authors before submission for publication.

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