ಕರ್ನಾಟಕ ವಿಧಾನ ಪರಿಷತ್ತು

1. ಚುಕ್ಕೆ ಗುರುತಿಲ್ಲದ ಪ್ರಶ್ನೆ ಸಂಖ್ಯೆ : 2174
2. ಸದಸ್ಯರ ಹೆಸರು : ಶ್ರೀ ಶರವಣ ಟಿ.ಎ
3. ಉತ್ತರಿಸಬೇಕಾದ ದಿನಾಂಕ : 26.03.2026
4. ಉತ್ತರಿಸುವವರು : ಮಾನ್ಯ ಸಣ್ಣ ನೀರಾವರಿ, ವಿಜ್ಞಾನ ಮತ್ತು ತಂತ್ರಜ್ಞಾನ ಸಚಿವರು

ಕ್ರ. ಸಂ.	ಪ್ರಶ್ನೆ	ಉತ್ತರ
ಅ	ಕೆ.ಸಿ ವ್ಯಾಲಿ ಯೋಜನೆಯನ್ನು ಯಾವಾಗ ಪ್ರಾರಂಭಿಸಲಾಯಿತು; ಪ್ರಸ್ತುತ ಯೋಜನೆಗೆ ಸರ್ಕಾರ ಪ್ರತಿ ವರ್ಷ ಎಷ್ಟು ಹಣ ಖರ್ಚು ಮಾಡುತ್ತಿದೆ; ಯಾವ ಉದ್ದೇಶಗಳಿಗೆ ಖರ್ಚು ಮಾಡುತ್ತಿದೆ ಎನ್ನುವುದರ ಸಂಪೂರ್ಣ ಮಾಹಿತಿ ನೀಡುವುದು; (ಪ್ರಾರಂಭದಿಂದ ವರ್ಷವಾರು ಪ್ರತ್ಯೇಕ ಮಾಹಿತಿ ನೀಡುವುದು)	➢ ಬೆಂಗಳೂರು ನಗರದ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೋಲಾರ ಜಿಲ್ಲೆಯ ಹಾಗೂ ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಚಿಂತಾಮಣಿ ತಾಲ್ಲೂಕಿನ ಒಟ್ಟು 126 ಕೆರೆಗಳಿಗೆ ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆಯ ಮೊದನೇಯ ಹಂತದ ಕಾಮಗಾರಿಯನ್ನು ದಿನಾಂಕ: 24-06-2016 ರಂದು ಪ್ರಾರಂಭಿಸಿ, 2018-19 ನೇ ಸಾಲಿನಲ್ಲಿ ಪೂರ್ಣಗೊಂಡಿದ್ದು, ನಿರ್ವಹಣೆ ಯಲ್ಲಿರುತ್ತದೆ. **(ಕೆ.ಸಿ ವ್ಯಾಲಿ ಯೋಜನೆ 1ನೇ ಹಂತ)** ➢ ಇದರ ಮುಂದುವರೆದ ಭಾಗವಾಗಿ ದ್ವಿತೀಯ ಹಂತದಲ್ಲಿ 174 ಕೆರೆಗಳಿಗೆ ನೀರು ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆ ಕಾಮಗಾರಿಯನ್ನು ದಿನಾಂಕ: 13-05-2022 ರಂದು ಪ್ರಾರಂಭಿಸಲಾಗಿದ್ದು, ಪ್ರಸ್ತುತ ಕಾಮಗಾರಿ ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ. **(ಕೆ.ಸಿ ವ್ಯಾಲಿ ಯೋಜನೆ 2ನೇ ಹಂತ)** ಮೇಲ್ಕಂಡ ಯೋಜನೆಗಳಿಗಾಗಿ ಪ್ರಾರಂಭದಿಂದ ಇಲ್ಲಿಯವರೆಗಿನ ವರ್ಷವಾರು ವೆಚ್ಚದ ಮಾಹಿತಿಯನ್ನು ಅನುಬಂಧ-1 ರಲ್ಲಿ ನೀಡಲಾಗಿದೆ.
ಆ	ಕೆ.ಸಿ ವ್ಯಾಲಿ ಯೋಜನೆಯಡಿಯಲ್ಲಿ ಪ್ರಸ್ತುತ ಎಷ್ಟು ಹಂತಗಳಲ್ಲಿ ನೀರನ್ನು ಸಂಸ್ಕರಿಸಲಾಗುತ್ತಿದೆ; ಮೂರನೇ ಹಂತದ ಸಂಸ್ಕರಣೆ ಮಾಡುವ ಪ್ರಸ್ತಾವನೆ ಸರ್ಕಾರದ ಮುಂದೆ ಇದೆಯೇ; ಇದ್ದಲ್ಲಿ, ಯಾವ ಕಾಲ ಮಿತಿಯಲ್ಲಿ ಜಾರಿ ಮಾಡಲಾಗುವುದು; ಇಲ್ಲದಿದ್ದಲ್ಲಿ, 3 ನೇ ಹಂತದ ಸಂಸ್ಕರಣೆ ಮಾಡದಿರಲು ಕಾರಣಗಳೇನು	ಕೋರಮಂಗಲ ಹಾಗೂ ಚಲ್ಲಘಟ್ಟ ಕಣಿವೆಯಲ್ಲಿರುವ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳಲ್ಲಿ ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣ ನಿಗದಿಪಡಿಸಿರುವ ಮಾನದಂಡಗಳಿಗೆ ಎರಡನೇ ಹಂತದಲ್ಲಿ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಸಂಸ್ಕರಿಸಲಾಗುತ್ತಿದೆ. ಮಾನ್ಯ ರಾಷ್ಟ್ರೀಯ ಹಸಿರು ನ್ಯಾಯಾಧಿಕರಣವು ಮೂಲ ದಾವೆ ಸಂ.1069/2018 ರ ಬಗ್ಗೆ ವಿಸ್ತೃತವಾದ ವಿಚಾರಣೆ ನಡೆಸಿ ದಿನಾಂಕ 30.04.2019 ರಂದು ಎಲ್ಲಾ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳ ಹೊರ ಹರಿವು ಈ ಕೆಳಕಂಡ ಮಾನದಂಡಗಳ ಮಿತಿಯೊಳಗೆ ಸಂಸ್ಕರಿಸಲು ಸೂಚಿಸಿರುತ್ತಾರೆ.

ನಿಯತಾಂಕ	ಸಂಸ್ಕರಿಸಿ ಹೊರಸೂಸುವ ಮಾನ ದಂಡಗಳು
ನೀರಿನ ಆಮ್ಲೀಯತೆ (pH)	5.5 – 9.0
ಜೈವಿಕ ಆಮ್ಲಜನಿಕದ ಬೇಡಿಕೆ (ಮಿ.ಗ್ರಾ/ಲೀ)	10
ಒಟ್ಟು ತೇಲುವ ಘನಗಳು (ಮಿ.ಗ್ರಾ/ಲೀ)	20
ರಾಸಾಯನಿಕ ಆಮ್ಲಜನಿಕದ ಬೇಡಿಕೆ (ಮಿ.ಗ್ರಾ/ಲೀ)	50
ಒಟ್ಟು ಸಾರಜನಕ (ಮಿ.ಗ್ರಾ/ಲೀ)	10
ಒಟ್ಟು ರಂಜಕ (ಮಿ.ಗ್ರಾ/ಲೀ)	1.0
ಫೀಕಲ್ ಕೋಲಿಫಾರ್ಮ್ (ಹೆಚ್ಚು ಸ.ಸಂ)	<100

ಈ ಹಿನ್ನಲೆಯಲ್ಲಿ ಮಾನ್ಯ ರಾಷ್ಟ್ರೀಯ ಹಸಿರು ನ್ಯಾಯಾಧಿಕರಣವು ಬೆಳ್ಳಂದೂರು ಮತ್ತು ವರ್ತೂರು ಕೆರೆಗಳಿಗೆ ಸಂಬಂಧಿಸಿದ ಮೂಲ ದಾವೆ 125/2017 ರ ಬಗ್ಗೆ ವಿಸ್ತೃತವಾದ ವಿಚಾರಣೆ ನಡೆಸಿ, ದಿನಾಂಕ 18.12.2019 ರ ಆದೇಶದಲ್ಲಿ ಮೇಲೆ ತಿಳಿಸಿದ ದಾವೆ ಸಂ.1069/2018 ರ ದಿನಾಂಕ 30.04.2019 ರ ಆದೇಶದಲ್ಲಿ ನಿಗದಿಪಡಿಸಿರುವ ಮಾನದಂಡಗಳ ಮಿತಿಯೊಳಗೆ ಬೆಳ್ಳಂದೂರು ಕೆರೆಯ ಜಲಾನಯನ ಭಾಗವಾಗಿರುವ ಎಲ್ಲಾ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳ ಹೊರ ಹರಿವನ್ನು ಸಂಸ್ಕರಿಸಲು ಆದೇಶಿಸಿರುತ್ತಾರೆ.

ಬಿ ನಾಗಸಂದ್ರದ, ಕೋರಮಂಗಲ ಹಾಗೂ ಚಲ್ಲಘಟ್ಟ ಕಣಿವೆಯಲ್ಲಿರುವ 248 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯಧ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕದ ಉನ್ನತೀಕರಣದ ಕಾಮಗಾರಿಯನ್ನು ಬೆಂಗಳೂರು ಜಲಮಂಡಳಿಯು ಕೈಗೆತ್ತಿಕೊಂಡಿದ್ದು, ಸದರಿ ಕಾಮಗಾರಿಯನ್ನು ಗುತ್ತಿಗೆದಾರರಾದ M/s SUEZ India Pvt Ltd ರವರಿಗೆ ನೀಡಲಾಗಿದ್ದು, ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ. ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು.

ಮುಂದುವರೆದು, ಬಿ ನಾಗಸಂದ್ರದ, ಕೋರಮಂಗಲ ಕಣಿವೆಯಲ್ಲಿರುವ 150 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯದ ತ್ಯಾಜ್ಯ

		ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕದಲ್ಲಿ ಈಗಾಗಲೇ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುತ್ತಿದೆ ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುತ್ತಿದೆ. ಬೆಳ್ಳಂದೂರಿನಲ್ಲಿರುವ 90 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯದ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳಲ್ಲಿಯು ಸಹ ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು ಸದರಿ ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿದೆ. ಕೋರಮಂಗಲ ಹಾಗೂ ಚಲ್ಲಘಟ್ಟ ಕಣಿವೆಯಲ್ಲಿರುವ 60 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯದ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳಲ್ಲಿಯು ಸಹ ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು ಸದರಿ ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ ಹಾಗೂ ಏಪ್ರಿಲ್ 2026 ರ ಅಂತ್ಯದಲ್ಲಿ ಕಾರ್ಯಾರಂಭ ಮಾಡಲಾಗುವುದು. ಕಾಡಬೀಸನಹಳ್ಳಿಯಲ್ಲಿರುವ 50 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯಧ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕದ ಉನ್ನತೀಕರಣದ ಕಾಮಗಾರಿಯನ್ನು ಬೆಂಗಳೂರು ಜಲಮಂಡಳಿಯು ಕೈಗೆತ್ತಿಕೊಂಡಿದ್ದು, ಸದರಿ ಕಾಮಗಾರಿಯನ್ನು ಗುತ್ತಿಗೆದಾರರಾದ M/s Toshiba Water Solutions Pvt. Ltd., ರವರಿಗೆ ನೀಡಲಾಗಿದ್ದು, ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ. ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು.
ಇ	ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟದ ಬಗ್ಗೆ ಮೇಲ್ವಿಚಾರಣೆ ಹಾಗೂ ಮೌಲ್ಯಮಾಪನ ಮಾಡುತ್ತಿರುವ ಸಂಸ್ಥೆ ಯಾವುದು; ಸದರಿ ಸಂಸ್ಥೆಯು ನೀಡಿರುವ ದತ್ತಾಂಶ/ವರದಿಯ ಮಾಹಿತಿ	ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ಕೆರೆಗಳಿಗೆ ತುಂಬಿಸಲಾಗುತ್ತಿರುವ ನೀರಿನ ಗುಣಮಟ್ಟದ ಬಗ್ಗೆ ಮೇಲ್ವಿಚಾರಣೆ ಹಾಗೂ ಮೌಲ್ಯಮಾಪನ ಮಾಡಲು "ಸೊಸೈಟಿ ಫಾರ್ ಇನೋವೇಷನ್ & ಡೆವೆಲಪ್‌ಮೆಂಟ್ ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆ" ಇವರಿಗೆ ದಿನಾಂಕ:03/03/2020 ರಂದು ವಹಿಸಲಾಗಿರುತ್ತದೆ.

ನೀಡುವುದು; ನಿರ್ವಹಣೆಯನ್ನು ಅದೇ ಸಂಸ್ಥೆಗೆ ವಹಿಸಲು ಕಾರಣಗಳೇನು;

ಸದರಿ ಸಂಸ್ಥೆಯವರು ಕಾಲ ಕಾಲಕ್ಕೆ ನೀಡುವ ದತ್ತಾಂಶ/ವರದಿಯಲ್ಲಿನ ಅಂಶಗಳು ಈ ಕೆಳಕಂಡಂತಿರುತ್ತದೆ;

ಈ ಯೋಜನೆಯಿಂದ ತುಂಬಿಸುತ್ತಿರುವ ನೀರಿನ ಗುಣ ಮಟ್ಟವನ್ನು ಪೂರ್ವಭಾವಿಯಾಗಿ ಪರಿಶೀಲಿಸಲಾಗುತ್ತಿದ್ದು, ನೀರಿನ ಗುಣ ಮಟ್ಟವು ಸಿ.ಪಿ.ಸಿ.ಬಿ. ಮತ್ತು ಎನ್.ಜಿ.ಟಿ. ಮಾನ ದಂಡಗಳಿಗೆ ಅನುಗುಣವಾಗಿ ಇರುತ್ತದೆ. ಕೆ.ಸಿ.ವ್ಯಾಲಿ STP ಬಳಿ ಹಾಗೂ ಯೋಜನೆಯ ಚೌಡೇನಹಳ್ಳಿ ಕೆರೆಯ ನೀರಿನ ಗುಣಮಟ್ಟದ ವಿವರಗಳು ಈ ಕೆಳಗಿನಂತಿದೆ;

Parameters	NGT Standard	CPCB (Designated best – use water quality	STW from the outlet of STP	Chowdenahalli tank
Ph	6.5-9.0	6.5-8.5	7.6	7.4
BOD	10	≤2, ≤3	9 ± 1	3.7 ± 0.8
DO (mg/l)	NS	≥6, ≥5, ≥4	4.5	8.5 ± 2.1

ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ನೀರನ್ನು ನೇರವಾಗಿ ಕೃಷಿ ಚಟುವಟಿಕೆಗಳಿಗೆ ನೀಡಲಾಗುತ್ತಿರುವುದಿಲ್ಲ. ಕೆರೆಗಳಿಗೆ ನೀರು ತುಂಬಿಸುವುದರಿಂದ ಅಂತರ್ಜಲ ಅಭಿವೃದ್ಧಿಯಾಗಿ ರೈತರು ತಮ್ಮ ತೆರೆದ ಬಾವಿ, ಕೊಳವೆ ಬಾವಿಗಳಿಂದ ಕೃಷಿ ಚಟುವಟಿಕೆಗಳಿಗೆ ನೀರನ್ನು ಬಳಸುತ್ತಿದ್ದಾರೆ. ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ಒದಗಿಸಲಾಗುತ್ತಿರುವ ನೀರನ್ನು ನೇರವಾಗಿ ಕೃಷಿ ಚಟುವಟಿಕೆಗಳಿಗೆ ಉಪಯೋಗಿಸುವ ಕುರಿತು ಹಾಗೂ ಈ ನೀರಿನ ಬಳಕೆಯಿಂದ ಕೃಷಿ ಉತ್ಪನ್ನಗಳ ಮೇಲೆ ಉಂಟಾಗಬಹುದಾದ ಪರಿಣಾಮಗಳ ಕುರಿತು ಅಧ್ಯಯನ ವರದಿಯನ್ನು ಜುಲೈ 2023 ರಲ್ಲಿ ನೀಡಿರುತ್ತಾರೆ. ವರದಿಯ ಸಾರಾಂಶವು ಈ ಕೆಳಕಂಡಂತಿರುತ್ತದೆ. ದತ್ತಾಂಶ/ವರದಿಯನ್ನು ಅನುಬಂಧ-2 ರಲ್ಲಿ ಲಗತ್ತಿಸಿದೆ.

"......The outcomes of study indicated no negative impact on soil properties when using indirectly recharged Ground water (GW) where as a positive significant impact was reduced soil salinity in impacted areas. No microbiological contamination in terms of pathogens was found on tested soil and crop samples. Hence, indirectly recharged Ground water (GW) using Secondary treated water(STW) could be safely used as an alternative source for irrigation overcoming the concerns of heavy metal and micro contaminants and pathogens associated with the direct use of partially treated or untreated mixed municipal Waste

		Water (WW) for irrigation…." ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆರವರು ಅಧ್ಯಯನ ಮಾಡಿ ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ತುಂಬಿಸಿರುವ ಕೆರೆಗಳ ಸುತ್ತಮುತ್ತಲಿನ ಪ್ರದೇಶಗಳಲ್ಲಿ ಸಂಶೋಧನೆಯನ್ನು ಕೈಗೊಂಡು ವರದಿಯನ್ನು ದಿನಾಂಕ:08.11.2023 ರಂದು ನೀಡಿರುತ್ತಾರೆ. ವರದಿಯ ಸಾರಾಂಶವು ಈ ಕೆಳಕಂಡಂತಿರುತ್ತದೆ. ದತ್ತಾಂಶ/ವರದಿಯನ್ನು ಅನುಬಂಧ-3ರಲ್ಲಿ ಲಗತ್ತಿಸಿದೆ. "……***The secondary treated water which is being pumped to Kolar from Secondary treated plant (STP) at K & C Valley and Bellandur does not contain any harmful heavy metals above the prescribed limit even as per drinking water standards IS:10500:2012……."*** ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆರವರು ಅಧ್ಯಯನ ಮಾಡಿ ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ತುಂಬಿಸಿರುವ ನೀರಿನ ಗುಣಮಟ್ಟದ ವರದಿಯನ್ನು ದಿ: 08.08.2025 ರಲ್ಲಿ ಹಾಗೂ ಕೆರೆಗಳ ಸುತ್ತಮುತ್ತಲಿನ ಪ್ರದೇಶಗಳಲ್ಲಿ ಸಂಶೋಧನೆಯನ್ನು ಕೈಗೊಂಡು ವರದಿಯನ್ನು ದಿ:29.09.2025 ರಂದು ಈ ಕೆಳಗಿನಂತೆ ನೀಡಿರುತ್ತಾರೆ. • The impacted tanks surface water quality meets the Honorable NGT standards for all parameters except E-coli. • The impacted tanks surface water quality is better than the rain fed non impacted water quality. • The heavy metals are not detected in the surface water of impacted and non- impacted tanks. The heavy metal levels are meeting drinking water standards IS10500:2012. • The ground water quality post KC valley project has significantly improved for all the parameters • The heavy metals are not detected in the ground water of impacted tanks. The heavy metal levels are meeting drinking water standards IS10500:2012 • KC valley, the ground levels have significantly improved • The water quality at the DC point meets the Honorable NGT standards for all parameters except for E- coli. • The heavy metals are not detected in the STP final treated water reaching at the DC point of kolar. In fact, The heavy metal levels are meeting drinking water standards IS10500:2012 • Based on data collected in this study from the

Directorate of Health and Family Welfare Services, Government of Karnataka, the analysis indicates that the reuse of secondary treated wastewater for indirect groundwater recharge through the Soil Aquifer Treatment technique does not adversely affect public health. On the contrary, improvements in hygiene and WASH scores were observed, as evidenced by the decline in waterborne diseases. This positive outcome can be attributed to better water availability, improved sanitation and hygiene practices, and enhanced nutritional intake. In the context of growing water scarcity, particularly in semi-arid regions, decision-makers should prioritize and support projects that strengthen water security through sustainable water reuse. Overall, this study recommends that policymakers actively promote the reuse of treated wastewater for indirect groundwater recharge.

ದತ್ತಾಂಶ/ವರದಿಯ ಪ್ರತಿಯನ್ನು ಅನುಬಂಧ-4ರಲ್ಲಿ ಲಗತ್ತಿಸಿದೆ.

ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆರವರ ಅಧ್ಯಯನದ ವರದಿ ದಿ:29.01.2026 ರಲ್ಲಿ ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ತುಂಬಿಸಿರುವ ನೀರಿನ ಅಂತರ್ಜಲ ಗುಣಮಟ್ಟ ಮತ್ತು ನೀರಿನ ಮಟ್ಟದಲ್ಲಿ ಆಗಿರುವ ಸುಧಾರಣೆಯ ಕುರಿತು ಈ ಕೆಳಕಂಡಂತೆ ನೀಡಿರುತ್ತಾರೆ.

- Groundwater-level analysis indicates a marked and sustained rise in water levels in impacted locations following implementation of the KC Valley project, irrespective of precipitation variability, confirming recharge-driven aquifer response.
- During the pre-recharge period (2014–2018), declining groundwater levels corresponded with elevated concentrations of total dissolved solids (TDS), hardness, chloride (Cl^-), sodium adsorption ratio (SAR), and electrical conductivity (EC), indicating degraded groundwater quality conditions.
- Post-recharge observations (2019–2025) show a consistent reduction in TDS, hardness, Cl^-, SAR, and EC in impacted locations, reflecting the influence of dilution and recharge processes.
- Comparative analysis further indicates that impacted locations exhibit better groundwater quality than non-impacted locations during the post-recharge

period, particularly with respect to salinity- and sodicity-related indicators.

- The combined improvement in groundwater levels and reduction in key hydro chemical parameters demonstrates the positive impact of the KC Valley recharge intervention on aquifer quantity and quality in the impacted Kolar region.

ದತ್ತಾಂಶ/ವರದಿಯ ಪ್ರತಿಯನ್ನು ಅನುಬಂಧ-5ರಲ್ಲಿ ಲಗತ್ತಿಸಿದೆ.

ಮುಂದುವರೆದು, ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆರವರ ಇತ್ತೀಚಿನ ಅಧ್ಯಯನದ ವರದಿ ದಿ:02.03.2026 ರಲ್ಲಿ ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ತುಂಬಿಸಿರುವ ನೀರಿನ (Level of water treatment) ಕುರಿತು ಈ ಕೆಳಕಂಡಂತೆ ನೀಡಿರುತ್ತಾರೆ.

(1) an anaerobic decomposition during travel to STPs which precipitates heavy metals and transfers them to the sludge, even if they ever enter this stream accidentally

(2) a retrofitted aerobic sewage treatment system which meets the stringent discharge standards set by the NGT-the STPs ensure removal of most of the household chemicals including domestic surfactants

(3) when the treated wastewater travels a distance of 53 km in the closed pipe from STP to Kolar region taking about 22h, any residual organic compound gets biodegraded,

(4) the treated wastewater undergoes over 10-60 days of residence time in contact with an algal system in an open water body (tank/lake/kere) functioning like a polishing pond,

(5) Finally, the treated wastewater filters through tens of meters of soil contact before recharging groundwater. This gives the resident micro-organisms ample time to degrade any biodegradable compound that has escaped the earlier four stages. Further, the groundwater quality is also improved by diluting the hard groundwater with soft water (recharge water) as the added treated wastewater acts as a diluents reducing the ill effects of high fluoride and dissolved solids content of the deep aquifer groundwater, which was the case before the implementation of this project.

ದತ್ತಾಂಶ/ ವರದಿಯ ಪ್ರತಿಯನ್ನು ಅನುಬಂಧ-6ರಲ್ಲಿ ಲಗತ್ತಿಸಿದೆ.

		ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆರವರ ನೇತೃತ್ವದಲ್ಲಿ ತಜ್ಞರ ಸಮಿತಿಯನ್ನು ರಚಿಸಿ ಕೆ.ಸಿ ವ್ಯಾಲಿ ಯೋಜನೆಯನ್ನು ಕಳೆದ 5 ವರ್ಷಗಳಿಂದ ಅಧ್ಯಯನ ನಡೆಸಿ ನಿಗಾ ವಹಿಸಿರುತ್ತಾರೆ. ಮುಂದುವರೆದು, ಮೇಲ್ವಿಚಾರಣೆ ಹಾಗೂ ಮೌಲ್ಯಮಾಪನ ನಡೆಸಲು IISc ಸಂಸ್ಥೆಗೆ ವಹಿಸಲು ಕಾರಣಗಳು ಈ ಕೆಳಗಿನಂತಿವೆ. 1. ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆಯ (IISc) ತಾಂತ್ರಿಕ ವರದಿಗಳನ್ನು ಭಾರತೀಯ ಎಂಜಿನಿಯರಿಂಗ್ ಮತ್ತು ಸರ್ಕಾರಿ ಯೋಜನೆಗಳಲ್ಲಿ "ಅತ್ಯುನ್ನತ ಗುಣಮಟ್ಟದ" (Gold Standard) ದಾಖಲೆಗಳೆಂದು ಪರಿಗಣಿಸಲಾಗುತ್ತದೆ. 2. IISc ರವರ ತಾಂತ್ರಿಕ ವರದಿಗಳನ್ನು ನ್ಯಾಯಾಲಯದಲ್ಲಿ ಪುರಾವೆ, ಸಿಎಜಿ (CAG) ಮತ್ತು ರಾಜ್ಯ ಲೆಕ್ಕ ಪರಿಶೋಧನಾ ಇಲಾಖೆಗಳ ತಾಂತ್ರಿಕ ಪರಿಶೀಲನೆ ದೃಷ್ಟಿಯಲ್ಲಿ, IISc ಒಂದು ಸ್ವತಂತ್ರ ಮತ್ತು ನಿಷ್ಪಕ್ಷಪಾತ ಸಂಸ್ಥೆಯಾಗಿದೆ. 3. ಪ್ರಾದೇಶಿಕ ಸಮಸ್ಯೆಗಳಲ್ಲಿ ಭೂಮಿ ಮತ್ತು ಮಣ್ಣಿನ ದಾಖಲೆಗಳ ಉದಾಹರಣೆ: ಕೋಲಾರ ಅಥವಾ ಉತ್ತರ ಕರ್ನಾಟಕ ದಂತಹ ಪ್ರದೇಶಗಳಲ್ಲಿ ಮಣ್ಣಿನ ಸಾಮರ್ಥ್ಯ ಪರೀಕ್ಷೆ ಮತ್ತು ಭೂಸ್ಥಿರತೆಯಲ್ಲಿ ವರದಿಗಳಿಗಾಗಿ ವಿಶೇಷ ಪರಿಣತಿ ಹೊಂದಿರುತ್ತದೆ. 4. IISc ಒಂದು "ರಾಷ್ಟ್ರೀಯ ಪ್ರಾಮುಖ್ಯತೆಯ ಸಂಸ್ಥೆ" (Institute of Eminence) ಆಗಿರುವುದರಿಂದ, ಅವರ ವರದಿಗಳನ್ನು ಕೇವಲ "ಸಲಹೆ" ಎಂದು ಪರಿಗಣಿಸದೆ, ವಿಜ್ಞಾನ ಸಮ್ಮತ ತೀರ್ಪು ಎಂದು ಪರಿಗಣಿಸಲಾಗುತ್ತದೆ. ಈ ಹಿನ್ನೆಲೆಯಲ್ಲಿ ಕೆ.ಸಿ.ವ್ಯಾಲಿ ಯೋಜನೆಯಿಂದ ಕೆರೆಗಳಿಗೆ ಒದಗಿಸಲಾಗುತ್ತಿರುವ ನೀರನ್ನು ನೇರವಾಗಿ ಕೃಷಿ ಚಟುವಟಿಕೆಗಳಿಗೆ ಉಪಯೋಗಿಸುವ ಬಗ್ಗೆ ಹಾಗೂ ಪರಿಸರ (Environmental impact assessment) ಅಡಿಯಲ್ಲಿ Long term impact ಹಾಗೂ Uranium Studies ಬಗ್ಗೆ ಅಧ್ಯಯನವನ್ನು ಭಾರತೀಯ ವಿಜ್ಞಾನ ಸಂಸ್ಥೆ (Center for Sustainable Technologies, IISC. Bengaluru) ರವರ ಮುಖಾಂತರ ಕೈಗೊಳ್ಳಲು ಕರ್ನಾಟಕ ಸಾರ್ವಜನಿಕ ಸಂಗ್ರಹಣೆಗಳಲ್ಲಿ ಪಾರದರ್ಶಕತೆ ಅಧಿನಿಯಮ-1999 ರ ಕಲಂ 4(ಜಿ) ರಡಿ ವಿನಾಯಿತಿ ನೀಡಿ ಸದರಿ ಸಂಸ್ಥೆಗೆ ಮತ್ತೊಮ್ಮೆ ವಹಿಸಲು ಅನುಮೋದನೆ ನೀಡಲಾಗಿರುತ್ತದೆ.

ಈ	ಸದರಿ ಯೋಜನೆಯಡಿಯಲ್ಲಿ ಎನ್.ಜಿ.ಟಿ ನೀಡಿದ ನಿರ್ದೇಶನ ದಂತೆ ಎಷ್ಟು ಎಸ್.ಟಿ.ಪಿ ಗಳನ್ನು ಮೇಲ್ದರ್ಜೆಗೆ ಏರಿಸಲಾಗಿದೆ; ಹಾಗೂ ಮೇಲ್ದರ್ಜೆಗೆ ಏರಿಸಲು ಎಷ್ಟು ಬಾಕಿ ಇವೆ; ಬಾಕಿಗೆ ಕಾರಣಗಳು ಮತ್ತು ಯಾವ ಕಾಲಮಿತಿಯಲ್ಲಿ ಮೇಲ್ದರ್ಜೆಗೆ ಏರಿಸಲಾಗುವುದು?	ಸದರಿ ಯೋಜನೆಯಡಿಯಲ್ಲಿ ಎನ್.ಜಿ.ಟಿ ನೀಡಿದ ನಿರ್ದೇಶನದಂತೆ 4 ಎಸ್.ಟಿ.ಪಿ.ಗಳನ್ನು ಮೇಲ್ದರ್ಜೆಗೆ ಏರಿಸಲಾಗಿದೆ. ವಿವರಗಳು ಈ ಕೆಳಕಂಡಂತಿದೆ. 1. ಬಿ ನಾಗಸಂದ್ರದ. ಕೋರಮಂಗಲ ಹಾಗೂ ಚೆಲ್ಲಘಟ್ಟ ಕಣಿವೆಯಲ್ಲಿರುವ 248 ದಶ ಲಕ್ಷ ಲೀಟರ್ ಸಾಮರ್ಥ್ಯಧ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕದ ಉನ್ನತೀಕರಣದ ಕಾಮಗಾರಿಯನ್ನು ಬೆಂಗಳೂರು ಜಲಮಂಡಳಿಯು ಕೈಗೆತ್ತಿಕೊಂಡಿದ್ದು. ಸದರಿ ಕಾಮಗಾರಿಯನ್ನು ಗುತ್ತಿಗೆದಾರರಾದ M/s SUEZ India Pvt Ltd ರವರಿಗೆ ನೀಡಲಾಗಿದ್ದು. ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ. ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣ ದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು. ಸದರಿ ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿದ್ದು ಜುಲೈ 2026 ರ ಅಂತ್ಯದೊಳಗೆ ಪೂರ್ಣಗೊಳಿಸಲು ಯೋಜಿಸ ಲಾಗಿದೆ. . 2. ಬೆಳ್ಳಂದೂರಿನಲ್ಲಿರುವ 90 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯದ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳಲ್ಲಿಯು ಸಹ ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು ಸದರಿ ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತವೆ ಮತ್ತು ಸೆಪ್ಟೆಂಬರ್ 2026 ರ ಅಂತ್ಯದೊಳಗೆ ಪೂರ್ಣಗೊಳಿಸಲು ಯೋಜಿಸಲಾಗಿದೆ.

		3. ಕೋರಮಂಗಲ ಹಾಗೂ ಚಲ್ಲಘಟ್ಟ ಕಣಿವೆಯಲ್ಲಿರುವ 60 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯದ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕಗಳಲ್ಲಿಯು ಸಹ ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು ಸದರಿ ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ ಹಾಗೂ ಏಪ್ರಿಲ್ 2026 ರ ಅಂತ್ಯದಲ್ಲಿ ಕಾರ್ಯಾರಂಭ ಮಾಡಲಾಗುವುದು. 4. ಕಾಡಬೀಸನಹಳ್ಳಿಯಲ್ಲಿರುವ 50 ದ.ಲ.ಲೀ. ಸಾಮರ್ಥ್ಯಧ ತ್ಯಾಜ್ಯ ನೀರು ಸಂಸ್ಕರಣಾ ಘಟಕದ ಉನ್ನತೀಕರಣದ ಕಾಮಗಾರಿ ಯನ್ನು ಬೆಂಗಳೂರು ಜಲಮಂಡಳಿಯು ಕೈಗೆತ್ತಿ ಕೊಂಡಿದ್ದು, ಸದರಿ ಕಾಮಗಾರಿಯನ್ನು ಗುತ್ತಿಗೆ ದಾರರಾದ M/s Toshiba Water Solutions Pvt Ltd ರವರಿಗೆ ನೀಡಲಾಗಿದ್ದು, ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿ ರುತ್ತದೆ. ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ ತೃತೀಯ ಘಟಕವಾದ ಡಿಸ್ಕ್ ಫಿಲ್ಟರ್ ಅನ್ನು ಅಳವಡಿಸಿ ಸಂಸ್ಕರಿಸಲಾಗುವುದು ಹಾಗೂ ಸಂಸ್ಕರಿಸಿದ ನೀರಿನ ಗುಣಮಟ್ಟವನ್ನು ಕೆ.ಎಸ್.ಪಿ.ಸಿ.ಬಿ ಮತ್ತು ಹಸಿರು ನ್ಯಾಯಾಧೀ ಕರಣದ ನಿಯಂತಾಕಗಳಿಗೆ ಸಾಧಿಸಲಾಗುವುದು. ಸದರಿ ಕಾಮಗಾರಿಯು ಪ್ರಗತಿಯಲ್ಲಿದ್ದು ಮಾರ್ಚ್ 2027 ರ ಅಂತ್ಯ ದೊಳಗೆ ಪೂರ್ಣಗೊಳಿಸಲು ಯೋಜಿಸಲಾಗಿದೆ.

ಕಡತ ಸಂಖ್ಯೆ: MID 34 LCQ 2026

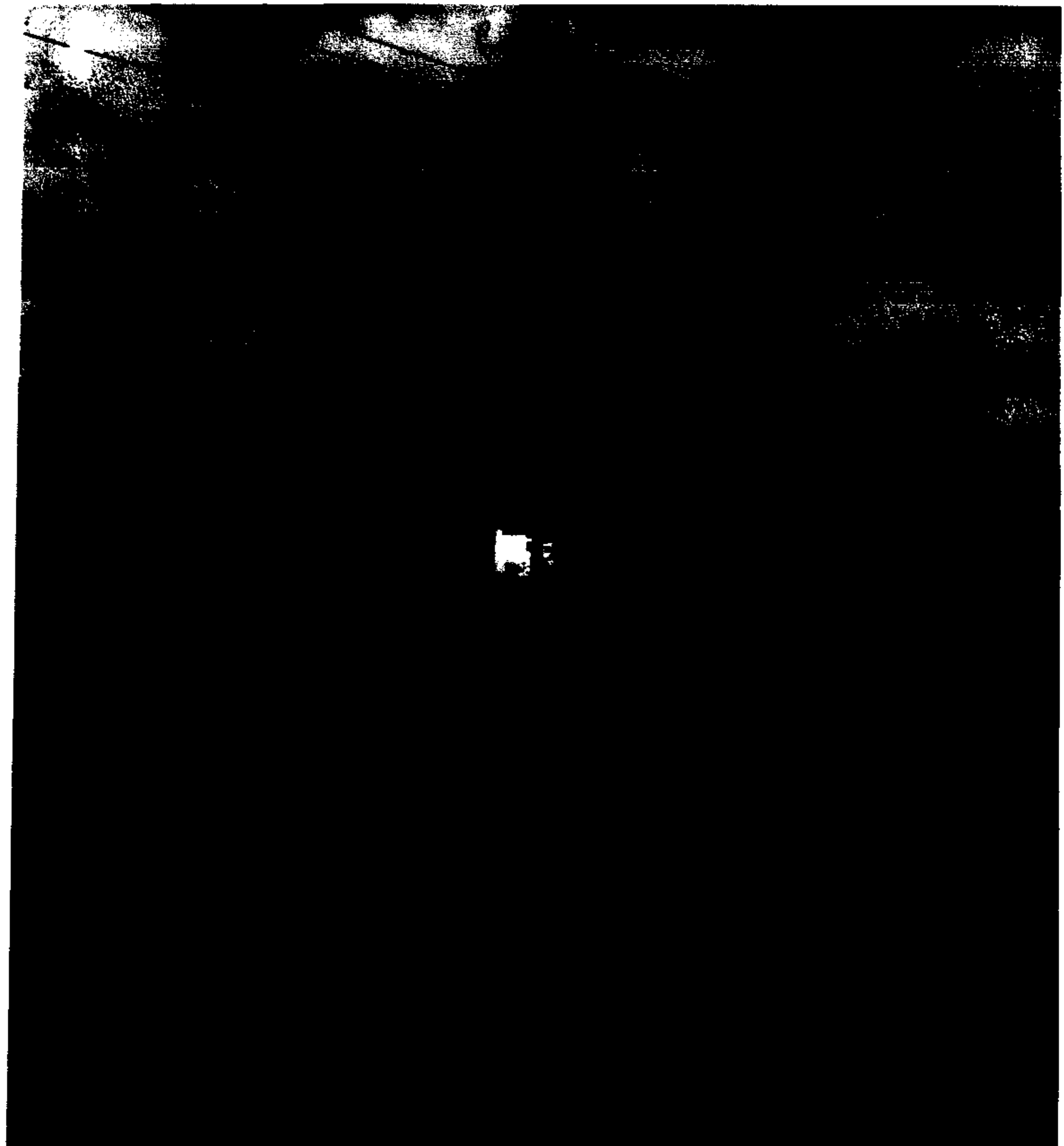
(ಎನ್.ಎಸ್. ಭೋಸರಾಜು)
ಸಣ್ಣ ನೀರಾವರಿ, ವಿಜ್ಞಾನ ಮತ್ತು
ತಂತ್ರಜ್ಞಾನ ಸಚಿವರು.

ವಿಧಾನ ಸಭೆಯ ಸದಸ್ಯರಾದ ಶ್ರೀ. ಶರವಣ ಟಿ.ಎ (ವಿಧಾನಸಭೆಯಿಂದ ಚುನಾಯಿತರಾದವರು) ರವರ ಚುಕ್ಕೆ ಗುರುತಿಲ್ಲದ ಪ್ರಶ್ನೆ ಸಂಖ್ಯೆ:2174 ಕ್ಕೆ ಅನುಬಂಧ -1

ಕ್ರ ಸಂ	ವಿಭಾಗ	ಜಿಲ್ಲೆ	ತಾಲ್ಲೂಕು	ಮತಕ್ಷೇತ್ರ	ಲೆಕ್ಕಶೀರ್ಷಿಕೆ	ಕಾಮಗಾರಿ ಹೆಸರು	ತಾಂತ್ರಿಕ ಮಂಜೂರಾತಿ ಸಂಖ್ಯೆ	ಗುತ್ತಿಗೆ ಮೊತ್ತ (ಜಿ.ಎಸ್.ಟಿ ಸೇರಿದಂತೆ)	ಗುತ್ತಿಗೆದಾರರ ಹೆಸರು	ಕಾಮಗಾರಿ ಪ್ರಾರಂಭಿಸಿದ ದಿನಾಂಕ	ವೆಚ್ಚ 2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	ಒಟ್ಟಾರೆ ವೆಚ್ಚ	ಕಾಮಗಾರಿಯ ಪ್ರಸ್ತುತ ಹಂತ
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	ಕೋಲಾರ	ಕೋಲಾರ	ಕೋಲಾರ ಮಾಲೂರು ಬಂಗಾರಪೇಟೆ ಮುಳಬಾಗಿಲು ಶ್ರೀನಿವಾಸಪುರ ಮತ್ತು	ಕೋಲಾರ ಮಾಲೂರು ಬಂಗಾರಪೇಟೆ ಮುಳಬಾಗಿಲು ಶ್ರೀನಿವಾಸಪುರ	LIS	ಬೆಂಗಳೂರು ನಗರ ಸಂಸ್ಕರಿಸಿ ಕೊಳಚೆ ನೀರನ್ನು ಕೋಲಾರ ಜಿಲ್ಲೆಯ ಹಾಗೂ ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಚಿಂತಾಮಣಿ ತಾಲ್ಲೂಕಿನ ಒಟ್ಟು 126 ಕೆರೆಗಳಿಗೆ ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆಯ ಕಾಮಗಾರಿ	CER NO 91/2015-16	134200	ಶ್ರೀ ಪಿ.ಪಿ ರೆಡ್ಡಿ, ಎಂ.ಡಿ, ಗುತ್ತಿಗೆದಾರರು, ಮೆ|| ಮೇಘಾ ಇಂಜಿನಿಯರಿಂಗ್ & ಇನ್ಫ್ರಾಸ್ಟ್ರಕ್ಚರ್ಸ್ ಲಿಮಿಟೆಡ್	8/24/2016	19053.50	73956.57	25650.92	8645.84	5547.32	400.00	105.06	1794.85	783.00	200.00	136536.86	ಸದರಿ ಕಾಮಗಾರಿಯಲ್ಲಿ 145 ಕೆರೆಗಳಿಗೆ ಸೇರಿಸಲಾಗಿದ್ದು, ಪ್ರಸ್ತುತ 143 ಕೆರೆಗಳಿಗೆ ಹಾಗೂ ಹಾಗೂ 113 ಚೆಕ್ ಡ್ಯಾಂಗಳಿಗೆ ನೀರನ್ನು ಹರಿಸಲಾಗಿರುತ್ತದೆ. ಉಳಿದ 02 ಕೆರೆಗಳಿಗೆ ನೀರನ್ನು ತುಂಬಿಸಬೇಕಾಗಿರುತ್ತದೆ. ಉಳಿದಂತೆ ಎಲ್ಲಾ ಲಿಫ್ಟ್‌ಗಳ Operation & Maintenance ಕಾಮಗಾರಿ ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ.
						ಬೆಂಗಳೂರು ನಗರದ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೋಲಾರ ಜಿಲ್ಲೆಯ ಹಾಗೂ ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಚಿಂತಾಮಣಿ ತಾಲ್ಲೂಕಿನ ಒಟ್ಟು 126 ಕೆರೆಗಳಿಗೆ ನೀರು ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆಯಿಂದ ಕೆ.ಸಿ ವ್ಯಾಲಿ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರಿನ ಮಾದರಿಗಳನ್ನು ಪ್ರತಿ ದಿನ ಬೆಳ್ಳಂದೂರು ಇನ್‌ಲೆಟ್ ಪಾಯಿಂಟ್ ಹತ್ತಿರ ಎನ್.ಜಿ.ಟಿ ಮತ್ತು ಸಿ.ಪಿ.ಸಿ.ಬಿ ಮಾರ್ಗಸೂಚಿಗಳನ್ವಯ ಹಾಗೂ MoEF&CCಯಲ್ಲಿ ನೋಂದಾಯಿತ ಪ್ರಯೋಗಾಲಯದಿಂದ ನೀರಿನ ಪರೀಕ್ಷೆಗಳನ್ನು ವಿಶ್ಲೇಷಣೆ ಮಾಡಿಕೊಡುವ ಕಾಮಗಾರಿ. (ಅಂದಾಜು ಮೊತ್ತ ರೂ. 53.00 ಲಕ್ಷಗಳು)			ಶ್ರೀ. ಚಂದನ ಎಸ್ ದಯಾಳ್, (ಎನ್ವಿರಾನ್‌ಮೆಂಟ್ ಹೆಲ್ತ್ & ಸೇಫ್ಟಿ ರಿಸರ್ಚ್ ಮತ್ತು ಡೆವಲಪ್‌ಮೆಂಟ್ ಸೆಂಟರ್)	23.02.2019	0.00	0.00	0.00	41.07	13.45	0.00	0.00	0.48	0.00	0.00	55.00	ಕಾಮಗಾರಿ ಪೂರ್ಣಗೊಂಡಿದೆ ಅಂತಿಮ ಬಿಲ್ಲು ಪಾವತಿಸಿದೆ
						Conducting Environmental Impact Assessment (EIA) for lifting / pumping 440 MLD secondary treated water from K & C Valley STP and Bellandur STP's to Narasapura Tank and onwards to fill 126 tanks in Kolar & Chickballapur Districts in Kolar District Karnataka State. (ಅಂದಾಜು ಮೊತ್ತ ರೂ. 338.00 ಲಕ್ಷಗಳು)			Society for Innovation and Development (IISc)	3/3/2020	0.00	0.00	0.00	0.00	237.00	56.00	50.50	0.00	22.00	48.50	414.00	Environmental Impact Assessment ಕಾಮಗಾರಿ ಅಧ್ಯಯನಕ್ಕೆ ಸಂಬಂಧಿಸಿದಂತೆ Society for Innovation and Development (IISc) ರವರು ವರದಿಗಳನ್ನು ದಿನಾಂಕ:14.01.2022 ರಿಂದ ಕಾಲಕಾಲಕ್ಕೆ ವರದಿಗಳನ್ನು ಸಲ್ಲಿಸುತ್ತಿದ್ದು, ಅಂತಿಮ ವರದಿ ಸ್ವೀಕೃತಗೊಂಡ ನಂತರ ಅಂತಿಮ ಬಿಲ್ಲನ್ನು ಪಾವತಿಸಲಾಗುವುದು.
						ಬೆಂಗಳೂರು ನಗರದ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೋಲಾರ ಜಿಲ್ಲೆಯ ಮತ್ತು ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಚಿಂತಾಮಣಿ ತಾಲ್ಲೂಕಿನ ಒಟ್ಟು 126 ಕೆರೆಗಳಿಗೆ ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆಯ ಪರಿಸರ ಪ್ರಭಾವ ಮೌಲ್ಯಮಾಪನ ಅಧ್ಯಯನ (Environmental Impact Assessment) ಅಡಿಯಲ್ಲಿ ಕೆ.ಸಿ ವ್ಯಾಲಿ ಮತ್ತು ಬೆಳ್ಳಂದೂರು ಪಂಪ್ ಹೌಸ್‌ಗಳಲ್ಲಿ ನೀರಿನ ಹರಿವನ್ನು ಮಾಪನ ಮಾಡಲು ಹಾಗೂ Flow Meterಗಳನ್ನು ಅಳವಡಿಸುವ ಕಾಮಗಾರಿ. (ಅಂದಾಜು ಮೊತ್ತ ರೂ. 80.00 ಲಕ್ಷಗಳು)			Society for Innovation and Development (IISc)													

ಕ್ರ. ಸಂ	ವಿಭಾಗ	ಜಿಲ್ಲೆ	ತಾಲ್ಲೂಕು	ಮತಕ್ಷೇತ್ರ	ಲೆಕ್ಕಶೀರ್ಷಿಕೆ	ಕಾಮಗಾರಿ ಹೆಸರು	ತಾಂತ್ರಿಕ ಮಂಜೂರಾತಿ ಸಂಖ್ಯೆ	ಗುತ್ತಿಗೆ ಮೊತ್ತ (ಜಿ.ಎಸ್.ಟಿ ಸೇರಿದಂತೆ)	ಗುತ್ತಿಗೆದಾರರ ಹೆಸರು	ಕಾಮಗಾರಿ ಪ್ರಾರಂಭಿಸಿದ ದಿನಾಂಕ	ವೆಚ್ಚ 2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	ಒಟ್ಟಾರೆ ವೆಚ್ಚ	ಕಾಮಗಾರಿಯ ಪ್ರಸ್ತುತ ಹಂತ
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
			ಚಿಂತಾಮಣಿ	ಮತ್ತು ಚಿಂತಾಮಣಿ		"ಬೆಂಗಳೂರು ನಗರದ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೋಲಾರ ಜಿಲ್ಲೆಯ ಹಾಗೂ ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಚಿಂತಾಮಣಿ ತಾಲ್ಲೂಕಿನ ಒಟ್ಟು 137 ಕೆರೆಗಳಿಗೆ ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆ ಕಾಮಗಾರಿಯ 440 ಎಂ.ಎಲ್.ಡಿ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೆ & ಸಿ ವ್ಯಾಲಿ ಎಸ್.ಟಿ.ಪಿ ಮತ್ತು ಬೆಳ್ಳಂದೂರು ಎಸ್.ಟಿ.ಪಿ ಮುಂದ ಸರಬರಾಜು ಕೆರೆಗೆ ತುಂಬಿಸುವ ಯೋಜನೆಯಡಿಯಲ್ಲಿ ಪರಿಸರ ನಿರ್ವಹಣಾ ಯೋಜನಾ (ಇ.ಎಂ.ಪಿ) ಕಾಮಗಾರಿ (ಅಂದಾಜು ಮೊತ್ತ ರೂ. 81.00 ಲಕ್ಷಗಳು)			Sri Shivanand M Dambal M/s Environmental Health & Safety Consultants Pvt Ltd	06/11/2020	0.00	0.00	0.00	0.00	18.13	0.00	50.00	0.00	2.23	12.31	80.67	ಕಾಮಗಾರಿ ಪೂರ್ಣಗೊಂಡಿದೆ ಅಂತಿಮ ಬಿಲ್ಲು ಪಾವತಿಸಿದೆ
						"ಬೆಂಗಳೂರು ನಗರದ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೋಲಾರ ಮತ್ತು ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಒಟ್ಟು 126 ಕೆರೆಗಳಿಗೆ ನೀರು ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆಯಿಂದ ತುಂಬಿಸಲಾಗುತ್ತಿರುವ 137 ಕೆರೆಗಳಲ್ಲಿ ಹಾಗೂ ಬೆಳ್ಳಂದೂರು ಜಾಕ್‌ವೆಲ್‌ನ ಇನ್‌ಲೆಟ್ ಬಳಿ IS ಮತ್ತು APHA ಮಾರ್ಗಸೂಚಿಗಳನ್ವಯ ಹಾಗೂ NABLನಿಂದ ಮಾನ್ಯತೆ ಪಡೆದಿರುವ ಹಾಗೂ ಪರಿಣತಿಯಲ್ಲಿ ತೊಡಗಿರುವ ಸಮಾಲೋಚಕರಿಂದ ನಿರಂತರ ಮಾದರಿಗಳನ್ನು ಕೈಗೊಳ್ಳಲು ಸಮಾಲೋಚಕರನ್ನು ನೇಮಿಸುವ ಕಾಮಗಾರಿ" (ಅಂದಾಜು ಮೊತ್ತ ರೂ. 158.00 ಲಕ್ಷಗಳು)			ಶ್ರೀ. ಚಂದನ ಎಸ್ ದಲಾಲ್, (ಎನ್ವಿರಾನ್‌ಮೆಂಟ್ ಟೆಕ್ & ಸೇಫ್ಟಿ ಕನ್ಸಲ್ಟೆಂಟ್ಸ್)	26/07/2021	0.00	0.00	0.00	0.00	0.00	19.36	59.16	36.63	41.89	0.00	157.04	ಕಾಮಗಾರಿ ಪೂರ್ಣಗೊಂಡಿದೆ ಅಂತಿಮ ಬಿಲ್ಲು ಪಾವತಿಸಿದೆ
						Study to conducted to assess the impact on agriculture from K & C Valley project			Society for Innovation and Development (IISc)	2/23/2023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.29	0.00	0.00	54.29	ಕಾಮಗಾರಿ ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ
						ಪಂಪ್‌ಹೌಸ್ ವಿದ್ಯುತ್ ಸರಬರಾಜು ಬಿಲ್ಲುಗಳ ವೆಚ್ಚ ಹಾಗೂ ಇತರೆ ವೆಚ್ಚಗಳು			Bescom	-	35.03	26.46	183.74	1019.22	1347.72	1564.60	1287.91	39.56	35.14	30.50	5569.88	ಸದರಿ ಕಾಮಗಾರಿಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಬಾಕಿಯಾದ ಬಿಲ್ಲು, ಇತರೆ ವೆಚ್ಚಗಳು ಹಾಗೂ ಪಂಪ್‌ಹೌಸ್ ವಿದ್ಯುತ್ ಸರಬರಾಜು ಬಿಲ್ಲುಗಳನ್ನು ಭರಿಸಲಾಗಿದೆ. 2023-24 ನೇ ಸಾಲಿನಿಂದ ಪ್ರತ್ಯೇಕವಾಗಿ ಬೆಸ್ಕಾಂ ಬಿಲ್ಲನ್ನು 2702-03-101-0-02-057 ವಿದ್ಯುತ್ ಸರಬರಾಜು ವೆಚ್ಚ, ಲೆಕ್ಕ ಶೀರ್ಷಿಕೆ ಅಡಿ ಭರಿಸಲಾಗುತ್ತಿದೆ.
										ಒಟ್ಟು	19088.53	73983.03	26034.66	9906.13	7161.62	2039.96	1552.63	1925.61	884.26	291.31	142867.74	

ಕ್ರ.ಸಂ	ವಿಭಾಗ	ಜಿಲ್ಲೆ	ತಾಲ್ಲೂಕು	ಮತಕ್ಷೇತ್ರ	ಲೆಕ್ಕಶೀರ್ಷಿಕೆ	ಕಾಮಗಾರಿ ಹೆಸರು	ತಾಂತ್ರಿಕ ಮಂಜೂರಾತಿ ಸಂಖ್ಯೆ	ಗುತ್ತಿಗೆ ಮೊತ್ತ (ಜಿ.ಎಸ್.ಟಿ ಸೇರಿದಂತೆ)	ಗುತ್ತಿಗೆದಾರರ ಹೆಸರು	ಕಾಮಗಾರಿ ಪ್ರಾರಂಭಿಸಿದ ದಿನಾಂಕ	ವೆಚ್ಚ											ಕಾಮಗಾರಿಯ ಪ್ರಸ್ತುತ ಹಂತ
											2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	ಒಟ್ಟಾರೆ ವೆಚ್ಚ	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	ಕೋಲಾರ	ಕೋಲಾರ	ಕೋಲಾರ ಮಾಲೂರು ಬಂಗಾರಪೇಟೆ ಮುಳಬಾಗಿಲು ಶ್ರೀನಿವಾಸಪುರ ಮತ್ತು ಚಿಂತಾಮಣಿ	ಕೋಲಾರ ಮಾಲೂರು ಬಂಗಾರಪೇಟೆ ಮುಳಬಾಗಿಲು ಶ್ರೀನಿವಾಸಪುರ ಮತ್ತು ಚಿಂತಾಮಣಿ	LIS	ಬೆಂಗಳೂರು ನಗರದ ಸಂಸ್ಕರಿಸಿದ ತ್ಯಾಜ್ಯ ನೀರನ್ನು ಕೋಲಾರ ಜಿಲ್ಲೆಯ ಹಾಗೂ ಚಿಕ್ಕಬಳ್ಳಾಪುರ ಜಿಲ್ಲೆಯ ಚಿಂತಾಮಣಿ ತಾಲ್ಲೂಕಿನ ಒಟ್ಟು 126 ಕೆರೆಗಳಿಗೆ ತುಂಬಿಸುವ ಏತ ನೀರಾವರಿ ಯೋಜನೆ ದ್ವಿತೀಯ ಹಂತದಲ್ಲಿ 174 ಕೆರೆಗಳಿಗೆ ನೀರು ತುಂಬಿಸುವ ಕಾಮಗಾರಿ	CER NO: 04/2020-21	46500.00	(1) ರಾಘವೇಂದ್ರ ಪಿ ಶೆಟ್ಟಿ, 2) ಮೆ|| ಆದಿತ್ಯ ಕನ್ಸ್‌ಟ್ರಕ್ಷನ್ ಕಂಪನಿ, 3) ಮೆ|| ಜಂಟಾ ಪ್ರಾಜೆಕ್ಟ್ಸ್ & ಇನ್ಫ್ರಾಸ್ಟ್ರಕ್ಚರ್ ಪ್ರೈವೇಟ್ ಲಿಮಿಟೆಡ್ ರವರೊಂದಿಗೆ ಜಾಯಿಂಟ್ ವೆಂಚರ್) 1ನೇ ದರ್ಜೆ ಗುತ್ತಿಗೆದಾರರು.	5/15/2022	0.00	0.00	0.00	0.00	225.03	0.00	5949.36	5905.69	3911.23	6107.02	22098.33	ಸದರಿ ಯೋಜನೆಯಲ್ಲಿ 09 ಪಂಪ್‌ಹೌಸ್‌ಗಳಿದ್ದು, 01 ಪಂಪ್‌ಹೌಸ್ Dry ರನ್ ಮತ್ತು ವೆಟ್ ರನ್ ಪೂರ್ಣಗೊಂಡಿದೆ. 03 ಪಂಪ್‌ಹೌಸ್‌ಗಳ Dry ರನ್ ಆಗಿದ್ದು, ನೀರು ಇಲ್ಲದ ಕಾರಣ ವೆಟ್ ರನ್ ಆಗಿರುವುದಿಲ್ಲ. 04 ಪಂಪ್‌ಹೌಸ್‌ಗಳ ಕಾಮಗಾರಿಗಳು ಶೇ. 80 ರಷ್ಟು ಮುಗಿದಿದ್ದು, ಆಗಸ್ಟ್ 2025ರ ಅಂತ್ಯಕ್ಕೆ ಪೂರ್ಣಗೊಳ್ಳುವುದು. ಉಳಿದ 01 ಪಂಪ್‌ಹೌಸ್ ಕಾಮಗಾರಿ ಸೆಪ್ಟೆಂಬರ್ 2025ರ ಅಂತ್ಯಕ್ಕೆ ಪೂರ್ಣಗೊಳ್ಳುವುದು. ಒಟ್ಟು 221 ಕಿ.ಮೀ ಉದ್ದದ ಪೈಪ್‌ಲೈನ್ ಪಂಕ್ತೀಕರಣದಲ್ಲಿ 174 ಕಿ.ಮೀ ಪೈಪ್‌ಲೈನ್ ಕಾಮಗಾರಿ ಪೂರ್ಣಗೊಂಡಿದ್ದು, ಉಳಿದ 47 ಕಿ.ಮೀ ಉದ್ದದ ಪೈಪ್‌ಲೈನ್ ಪಂಕ್ತೀಕರಣ ಕಾಮಗಾರಿ ಪ್ರಗತಿಯಲ್ಲಿರುತ್ತದೆ
										ಒಟ್ಟು	0.00	0.00	0.00	0.00	225.03	0.00	5949.36	5905.69	3911.23	6107.02	22098.33	
										ಒಟ್ಟು ವೆಚ್ಚ	19088.53	73983.03	26034.66	9906.13	7386.65	2039.96	7501.99	7831.30	4795.49	6398.33	164966.07	



Centre for Sustainable Technologies,

Indian Institute of Science, Bengaluru

July 2023

ANNEXURE-3

1. Introduction

The utilization of direct wastewater for irrigation poses many environmental problems. Concerns have arisen regarding the direct use of untreated wastewater (WW) for agricultural purposes. These concerns include the accumulation of organic matter and nutrients in sewage-farmed soils, referred to as "sewage sickness" (Antil, 2012; Kaur et al., 2012; Subrahmanyan, 1932); pathogen contamination of soil, leafy vegetables, and root crops (Shafiani and Malik, 2013); and potential health risks for farmers directly exposed to WW (Mehmood et al., 2019). Furthermore, the use of untreated WW may result in aesthetic issues, such as unpleasant odors, negatively impacting local communities and tourism (Jeong et al., ~~2016; Keraita et al., 2008)~~. This problem becomes more complex when domestic sewage mixed with industrial WW and urban runoff is used for agriculture. Particularly WW from industries like lead-acid battery recycling and electro-plating introduces various contaminants, including heavy metals, industrial detergents, and organic compounds (Yang et al., 2021; Mehmood et al., 2019; Rezapour et al., 2019; Libutti et al., 2018; Sou et al., 2012; Khan et al., 2008). These contaminants not only adversely affect soil quality and crop growth but also pose a risk of groundwater (GW) contamination in case of human consumption (Kristanti et al., 2021). Heavy metals, for example, can potentially translocate into plant roots, posing a threat to human health when consumed (Khan et al., 2015).

By synthesizing existing literature and addressing the drawbacks associated with the direct use of WW, this study presents an alternative, safe and sustainable soil aquifer treatment (SAT) based system for indirect GW recharge using secondary treated wastewater (STW) and its use for irrigation in semi-arid region. Thus, this study aims to quantify the impacts of using indirectly recharged groundwater for irrigation on soil properties and few of the crops.

2. Methodology

2.1 Site Description

In order to examine the impacts of STW recycling on GW recharge, GW quality, soil properties, and microbial distribution on harvested crops, four distinct sites were selected, both in impacted and non-impacted areas. The impacted sites were within the range of 10 km from the discharge point (DC) which is the receiving point for STW pumped from Bengaluru. STW is distributed to all 137 surface tanks from the DC point. The nonimpacted areas are comparatively far away (40 to 60 km) from the DC point and have rain-fed runoff as the only source of water recharging GW. The radial distance of the eight sites is almost the same from their nearby tanks in impacted and non-impacted areas to maintain uniformity (Table 1).

Table 1. Sample collection details

Sample ID	Sample name	Location		Radial Distance from DC point (km)	Radial Distance from nearest lake(km)	Water Levels (mbgl)
Impacted						
1.	A	13°07'26.7"N	77°57'46.7"E	0.2	0.2	19.4
2.	B	13°08'16.4"N	77°59'55.8"E	4.3	0.1	19.1
3.	C	13°07'45.3"N	78°01'59.3"E	7.7	0.5	25.6
4.	D	13°06'54.3"N	78°03'15.1"E	10.1	0.05	25.4
Non-impacted						
5.	E	13°10'20.8"N	78°21'32.4"E	43.4	0.4	58.1
6.	F	13°12'18.6"N	78°26'00.6"E	51.9	0.2	86.8
7.	G	13°12'55.2"N	78°27'00.1"E	53.9	0.1	87.4
8.	H	13°12'18.8"N	78°30'54.0"E	60.6	0.05	53.8

2.2 Characterization of soil

The surface composite soil samples (0-30 cm) were collected in triplicate from the identified impacted and non-impacted sites. Samples were collected, air-dried, sieved through a 2 mm sieve, and stored in plastic bags. The soil samples were analysed for various physicochemical properties such as soil texture, pH, EC, available nitrogen (N), available potassium (K), available phosphorus (P), SAR, and other micronutrients as per the standard procedure and methods described by Abegunrin et al., 2016; Pansu and Gautheyrou, 2006. The microbiological analysis of the soil samples was carried out by molecular biology procedures, including DNA extraction, PCR amplification, cluster generation, and 16S rRNA sequencing. The primers employed in the study, namely 16S rRNA F (GCCTACGGGNGGCWGCAG) and 16S rRNA R (ACTACHVGGGTATCTAATCC), were synthesized at Eurofins Genomics. After preparation, the amplicon library was purified using AMPure XP beads and quantified using a Qubit fluorometer. For the subsequent data analysis, the QIIME software platform was employed, and Eurofins Scientific Co. Ltd. (Bengaluru, India) facilitated the data analysis process (Mohan et al., 2021; Levantesi et al., 2010).

Additionally, the soil samples were also tested for the presence of other specific microbes such as *Escherichia coli (E.coli)*, and total coliform as indicator organisms and *Shigella*, and *Klebsiella* as representative pathogenic bacteria. The number of microorganisms studied was determined by the spread plate technique where 25 g of sample was added to 225 mL buffered peptone water, homogenized in a stomacher and then serial dilutions in buffered peptone water were spread onto agar plates which were incubated at 37°C for 24 hrs (Libutti et al., 2018). The selective and differential media used and the appearance of tested bacterial colonies are listed in Table 2.

Table 2. Specific media for pathogen identification (USEPA, 2002)

Specific differential media	Composition	Pathogen	Appearance
Eosin methylene blue agar	Peptone, Dipotassium hydrogen phosphate, Lactose, Saccharose (Sucrose), Eosin – Y, Methylene blue, Agar	*E.coli*, and total coliform	The green metallic sheen and Purple in colour
MacConkey agar	HMC peptone, gelatin peptone, lactose monohydrate, bile salt, sodium chloride, crystal Violet, natural red, Agar	*Klebsiella*, *Shigella*	Mucoid dark pink and Light pink and translucent

2.3 Microbiological analysis of harvested crops

To assess the impact of irrigation with indirectly recharged GW using recycled water, three harvested crops like beetroot (root crop), tomato (seasonal crop), and one leafy vegetable (spinach) were collected which were irrigated with drip irrigation in both impacted and non-impacted GW. A minimum of five plants of each crop were chosen randomly, and utmost care was taken to maintain aseptic conditions by using disposable gloves (Farhadkhani et al., 2018). All plant samples were collected in either sterile glass containers or plastic bags and promptly transported to the laboratory for subsequent microbiological analyses. To prepare the fresh plant samples for testing, the edible parts of each crop were gently washed with sterile tap water, and surface swabs were obtained for culturing in sterile tap water, following the methods outlined by (Obeng et al., 2018; Ugwu et al., 2014). The monitoring of indicator bacteria, specifically total coliforms and *E. coli*, along with a few common microbes such as *Shigella* and *Klebsiella* were analysed using the spread plate technique with specific selective differential media (details listed in Table 2).

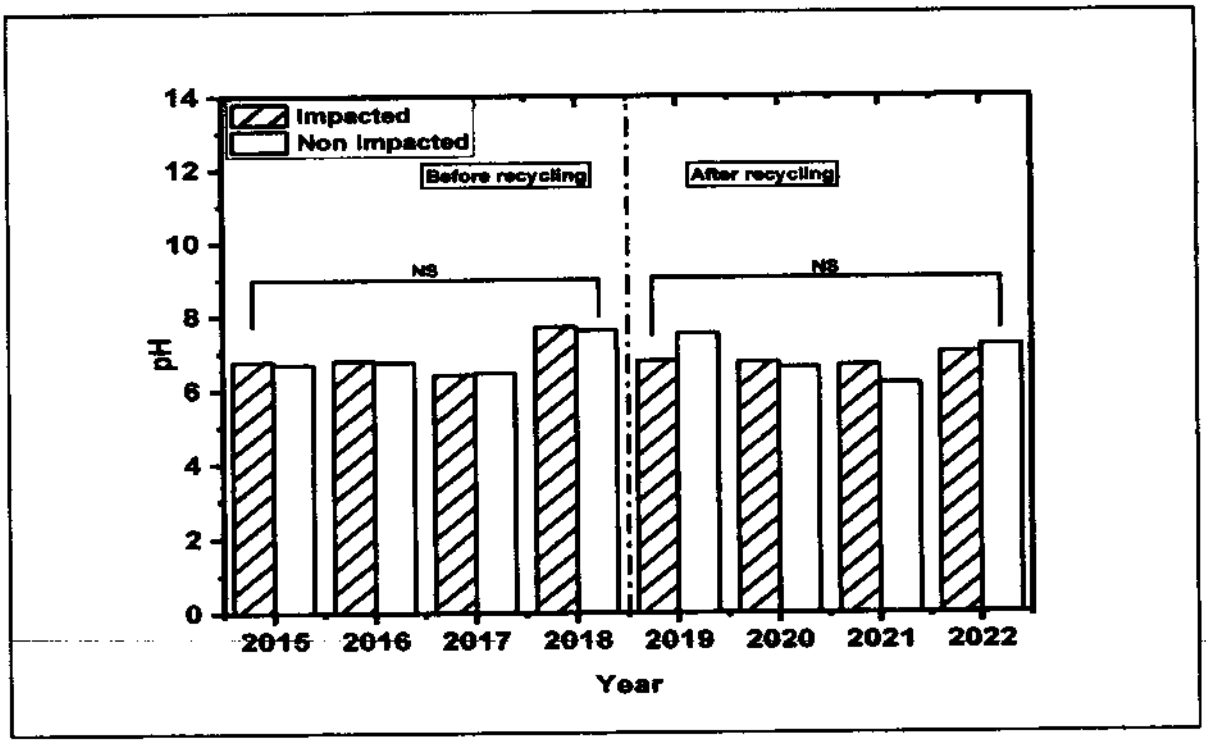
2.4 Groundwater quality

To assess the statistical significance of the obtained data (between before recycling and after recycling period), an independent Student's t-test was conducted. The outcomes of the t-test are presented as (a) NS (not significant) for $p > 0.05$, indicating no significant difference; (b) significant for $*p < 0.05$, denoting a statistically significant difference; and (c) highly significant for $**p < 0.01$, indicating a highly significant difference (Manisha et al., 2023).

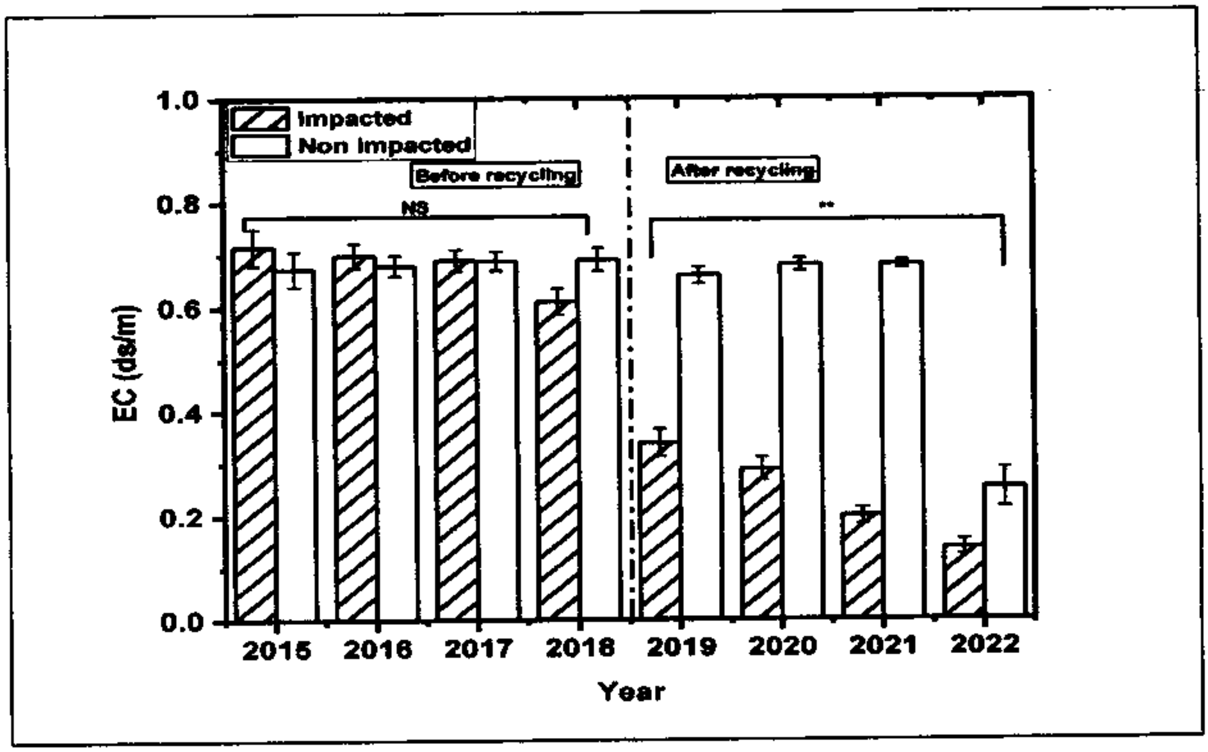
3. Results

3.1 Impact on soil properties

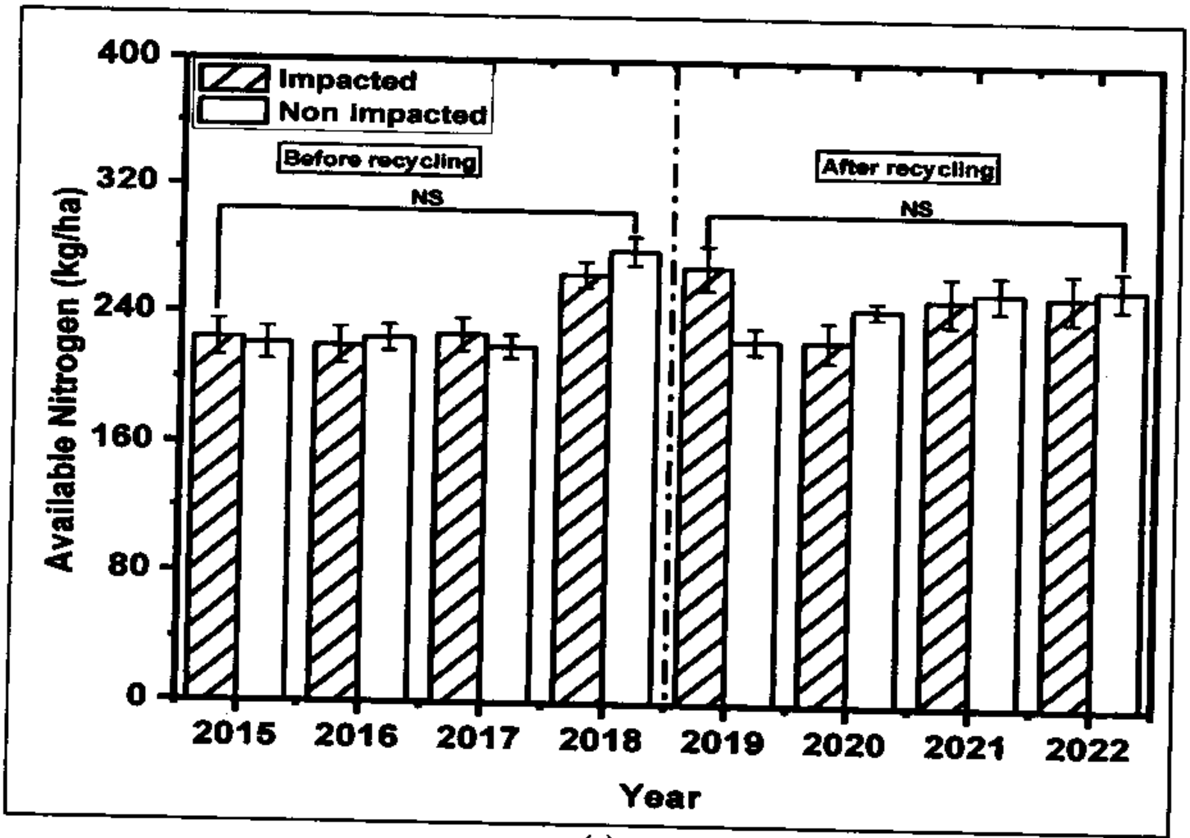
It is important to determine the impact of indirectly recharged GW using STW on soil properties during irrigation to evaluate safety and risk of contamination in soil and crop as well. It may be observed from Figure 1 that there was no statistically significant change (> 0.05) in the soil pH after the recycling project (after 2018). The pH of the soil was around 6.5 to 7.5 which is ideal for most of the crops. Soil pH affects nutrient availability in the soil as when the soil pH is too low or too high, some nutrients become less available to plants. A significant impact ($**p<0.01$) can be seen in the EC of impacted areas of soil wherein after recycling the EC reduced by 50% when compared with that before recycling. Whereas in non-impacted areas the soil was still saline with high EC. The reduction in the salinity of impacted soil can be correlated to the improved water quality of indirectly recharged GW used for irrigation. High levels of EC in non-impacted soil are mainly attributed to the original high levels of soluble salts in the GW used for irrigation which can lead to soil salinization and can limit crop growth and yield by impacting soil fertility. It can thus be concluded that there is no significant change in the soil properties such as available nitrogen (N), available potassium (K) and available phosphorous (P) where the indirectly recharged GW was used for irrigation.


Impacted
Non Impacted
Before recycling
After recycling
NS
NS
pH
Year
2015
2016
2017
2018
2019
2020
2021
2022

(a)

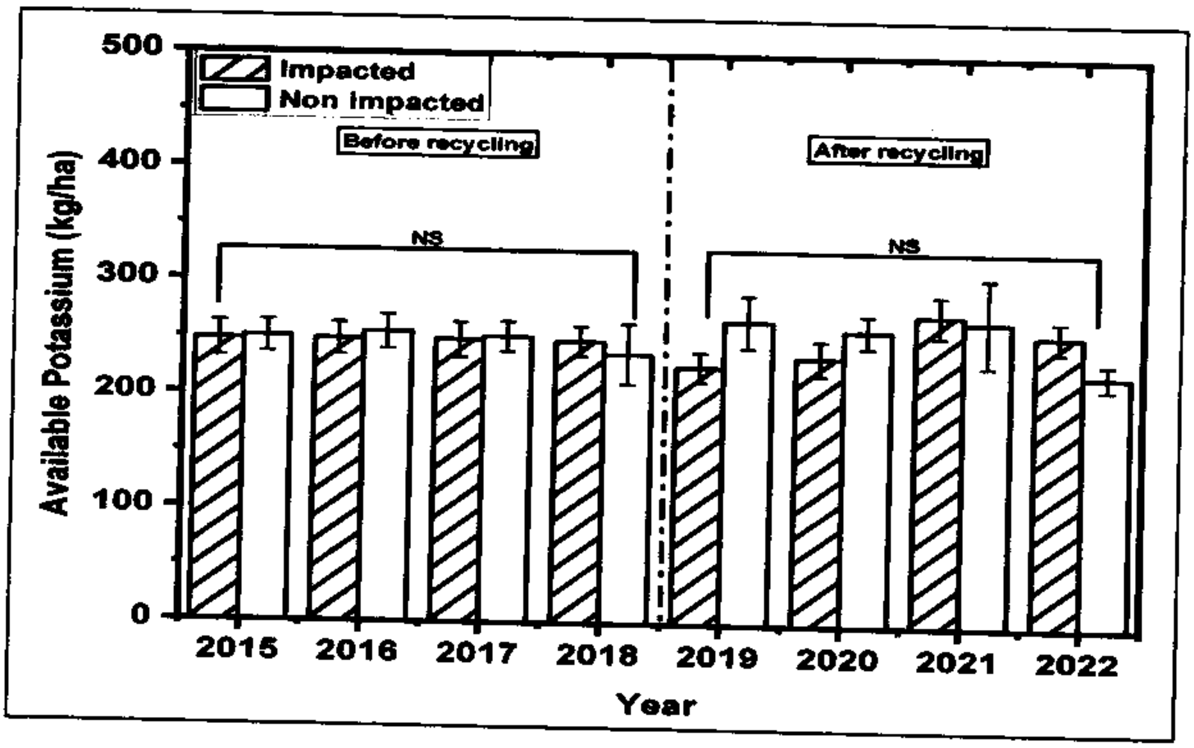

Impacted
Non Impacted
Before recycling
After recycling
NS
**
EC (ds/m)
Year
2015
2016
2017
2018
2019
2020
2021
2022

(b)



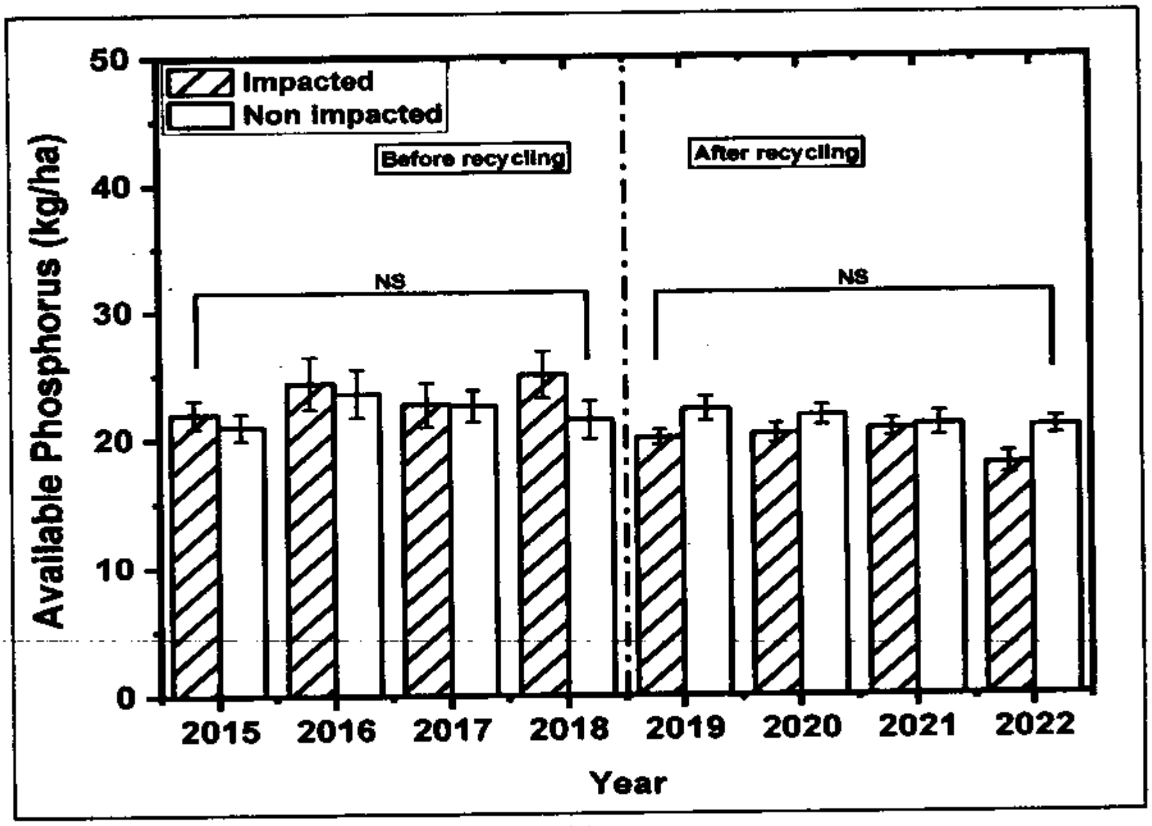
Impacted
Non impacted
Before recycling
After recycling
NS
NS
Available Nitrogen (kg/ha)
400
320
240
160
80
0
2015
2016
2017
2018
2019
2020
2021
2022
Year

(c)



Impacted
Non impacted
Before recycling
After recycling
NS
NS
Available Potassium (kg/ha)
500
400
300
200
100
0
2015
2016
2017
2018
2019
2020
2021
2022
Year

(d)



(e)

Figure 2: Soil Quality (a) pH, (b) EC, (c) Available Nitrogen, (d) Available Potassium, (e) Available Phosphorus

Table 3 presents a comparative study on the impact of using indirectly recharged GW on soil micronutrients and sodium absorption ratio (SAR). It can be observed that there was a significant improvement in the fertility status of soil in impacted areas as the salt deposition in the soil was less (SAR) which is attributed to the use of indirectly recharged GW which was soft in nature compared to the hard water from the deeper layer of the soil before the recycling project was initiated. A minor variation in other micronutrient concentrations can be observed as a result of dilution in impacted areas. Thus, it is concluded that there was no negative impact of using the indirectly recharged GW on soil properties when compared to the risk (like nutrient imbalance, heavy metal toxicity, soil salinization, microbial contamination, and reduced fertility) associated when STW is used directly for irrigation.

Table 3. Impact on micronutrient content and SAR of soils

S.No.	Parameters	Impacted Area		Non-impacted Area	
	(mg kg-1)	**Before recycling** (2016-2018)	**After recycling** (2019-2022)	**Before recycling** (2016-2018)	**After recycling** (2019-2022)
1.	Zinc	1.87 ± 0.09	1.05 ± 0.01	1.57 ± 0.2	1.77 ± 0.08
2.	Boron	1.59 ± 0.1	0.57 ± 0.06	1.82 ± 0.1	1.69 ± 0.2
3.	Iron	23.84 ± 1.2	11.62 ± 1.2	28.04 ± 2.2	24.55 ± 3.4
4.	Manganese	25.05 ± 1.6	18.68 ± 1.5	22.22 ± 1.8	25.01 ± 2.2
5.	Copper	1.4 ± 0.3	0.83 ± 0.01	1.9 ± 0.4	1.4 ± 0.01
6.	SAR (mEq/L)	5.7 ± 1.1	3.5 ± 0.9	5.5 ± 1.5	6.1 ± 1.8

Table 4 present microbiological load in soil. There was no considerable difference in the mean concentration of total coliform and *E. coli* in both impacted and non-impacted soil samples. It may be observed that non-impacted soil had only a marginally higher number of *E. coli* and total coliform in soil when compared with impacted soil, suggesting no significant impact of using indirectly recharged GW with STW on the microbial pathogen risks in cultivated soil. Since *E. coli* is one of the most important microbial indicators of fecal contamination, its presence in soil irrigated with non-impacted water could be due to any external environmental source of fecal contamination such as bird dropping, domestic animals, and open defecation (Edge and Hill, 2007). None of the marker pathogens studied (*Shigella, Klebsiella,*) were detected in soil samples.

Table 4. Microbiological load in soil

Sl.No.	Parameters	*E. coli* (CFU/g)	Total coliform (CFU/g)	*Shigella* (CFU/g)	*Klebsiella* (CFU/g)
1.	Impacted Soil	130 ± 5	1208 ± 20	N.D.	N.D.
2.	Non-impacted soil	144 ± 8	1330 ± 42	N.D.	N.D.

(Note: N.D.- Not detectable)

3.2 Soil health card of the experimental site

The health of the soil based on the parameters prescribed by the Indian Council of Agriculture Research (ICAR) and the Indian Institute of Soil Science (IISS) is presented in Table 5. It may be observed that most of the parameters such as available N, and available P fall under the medium category whereas available K falls under the higher category. Hence, it may be concluded that there was no significant difference in the soil health of the impacted and non-impacted areas confirming that there is no negative impact of irrigating agricultural fields with indirectly recharged GW and can be considered as a safe alternative for irrigation instead of using treated WW directly. After the commencement of the project due to the availability of water, farmers tended to cultivate cash and water-intensive crops (Tomato, ragi, paddy, carrot, cabbage, spinach, and fruits) over less water-intensive crops (Horse gram, ragi, and sometimes tomato if rainwater is available) (Manisha et al., 2023). A change in cropping pattern was also observed where in impacted areas farmers grew crops thrice in a year whereas in non-impacted areas once in a year.

Table 5. Soil health (GoI, 2017) based on parameters prescribed by ICAR and IISS

Sl.No.	Parameters	Impacted	Non-impacted
1.	Available N (High:>480 kg/ha; Medium: 240-480 kg/ha; Low: <240 kg/ha)	Medium	Medium
2.	Available K (High:>280 kg/ha; Medium: 110-280 kg/ha; Low: <110 kg/ha)	High	High
3.	Available P (High:>22 kg/ha; Medium: 11-22 kg/ha; Low: <11 kg/ha)	Medium	Medium

3.3 Bacterial diversity in soil

The dominant phylogenetic bacterial diversity and their specific role in the two soil samples (impacted and non-impacted) are presented in Table 6. A total of 14 bacterial phyla in common were observed in the two soil samples. *Proteobacteria* was the most abundant community (28–30%), followed by *Bacteroidetes* (10–15%), firmicutes (13-15%), *Acidobacteria* (12-15%), *Actinobacteria* (6-8%), *Planctomycetes* (6–7%), *Chlorofexi* (6–7%), *Verrucomicrobia* (2–3.5%), *Gemmatimonadetes* (1- 4.5%), *Nitrospirae* (1.5–2%) and few were the other groups. As seen from Table 1, there was no significant difference in the bacterial community concentration when compared in the two samples except for *Gemmatimonadetes* which are high in non-impacted soil as these are more prevalent in dry soils (DeBruyn et al., 2011). This indicates that the use of indirectly recharged GW for irrigation in impacted areas has no adverse effects on bacterial diversity. It can be observed from the role of the dominant phyla presented in Table 2 that most of them are plant growth promoters, few are major members in the nitrogen fixation cycle, few of them facilitate phosphorus and other micro-nutrient solubilization, few are involved in energy production and C metabolism, few of them secrete biofumigants and are associated in disease suppression by targeting pathogens (Malisorn et al., 2020; Li et al., 2020; Sharma and Salwan, 2018; Bruto et al., 2014). The outcomes of our study are in agreement with similar other studies (Ibekwe et al., 2018; Broszat et al., 2014) that have reported no significant impact on the overall diversity and richness of bacteria (depending on the quality of the treated WW) between soil irrigated with treated WW and synthetic freshwater. Table 6 also presents the comparison of phylogenetic bacterial diversity in soil when direct STW is used for irrigation.

Table 6. Soil health (GoI, 2017) based on parameters prescribed by ICAR and IISS

Sl. No.	Phylum	Impacted soil	Non-impacted soil	Secondary treated WW (Ibekwe et al., 2018)	Role	Reference
1	Proteobacteria	30.6% ± 5.4	28.2% ± 6.8	32.1% ± 5.1	• Plant growth-promoters (rhizobacteria) • Nitrogen fixation • Helps in phosphate and zinc solubilization • Produce Indole-3-acetic acid	• Malisorn et al., 2020
2	Bacteroidetes	14.7% ± 3.3	11.6% ± 2.7	1.62% ± 0.1	• Secrete diverse arrays of carbohydrates and active enzymes • Participate in energy production and conversion	• Lidbury et al., 2021
3	Firmicutes	14.2% ± 2.8	13.0% ± 1.4	26.5% ± 6.2	• Involved in cell wall biosynthesis • They are important chitinolytic bacteria • Play a role in the bio-control of plant pathogens in the phytoremediation of heavy metals	• Sharma and Salwan, 2018
4	Acidobacteria	14.3% ± 1.7	12.0% ± 3.0	3.1% ± 0.4	• Growth-promoting bacteria • Produce exopolysaccharides and modulate plant hormone level • Facilitate nitrogen, phosphorous, and iron acquisition	• Kielak et al., 2016
5	Actinobacteria	7.5% ±0.7	6.3% ± 1.8	14.3 ± 3.1	• Helps to solubilize phosphorus and potassium • Major role in nutrient cycling	• Li et al., 2020

					• Increase growth yield of staple crops like tomato • Potential destroyer of fungi and other bacteria that cause damage to plants • Associated with disease suppression	
6	Planctomycetes	6.7% ± 2.1	7.1% ± 1.4	0.8 ± 0.0	• Major role in the nitrogen cycle as can oxidize ammonia to dinitrogen without oxygen.	• Fuerst and Sagulenko, 2011
7	Chloroflexi	6.2% ± 1.4	7.0% ± 1.1	-	• Filamentous bacteria • Ferment carbohydrates and degrade other complex organic compounds	• Lidbury et al., 2021
8	Verrucomicrobia	3.4% ± 1.8	2.2% ± 0.5	0.19 ± 0.0	• Role in lipopolysaccharide biosynthesis and C metabolism	• Li et al., 2020
9	Gemmatimonadetes	1.0% ±0.3	4.2% ± 1.3	0.07 ± 0.0	• Important role in the cycling of organic C due to their metabolic strategies • These are more prevalent in drier soils	• Kielak et al., 2016
10	Nitrospirae	1.9% ± 0.2	1.6% ± 0.2	-	• Plays an important role in nitrification as a nitrite-oxidizing bacteria • Also provide ammonic oxidizers	• Fuerst and Sagulenko, 2011
11	Armatimonadetes	1.7% ± 0.4	1.4% ± 0.4	-	• No major role	• Lidbury et al., 2021
12	Crenarchaeota	0.1% ± 0.0	1.6% ± 0.1	-	• Involved in nitrogen cycle for ammonia oxidation	----
13	0D1	0.2% ± 0.0	1.2% ± 0.1	-	• No major role	----
14	WS3	0.1% ± 0.0	1.1% ± 0.0	-	• No major role	----

3.4 Microbial Load on crop

The use of wastewater (WW) for irrigation raises significant concerns regarding foodborne diseases linked to the consumption of contaminated produce. The indirect recharge of GW using STW was a concern for the contamination of crops. The microbial load of crops irrigated with indirectly recharged GW and non-impacted GW is presented in Table 7. It may be observed that none of the crop samples studied (except for spinach) contained detectable total coliforms, *E. coli* (an indicator of fecal contamination), and pathogens (*Shigella,* and *Klebsiella,*) suggesting no risk of infection on consuming these crops. As discussed earlier, the time between water being filled in the tanks and reaching GW recharge state can be as low as 1.5 years and this is far too long for pathogens to survive. It can be observed that a few total coliforms were detected on spinach (leafy vegetables) in both impacted and non-impacted areas suggesting human handling to be the major route rather than irrigation water. Hence, it is always recommended to wash and cook green leafy vegetables before direct consumption as they are most susceptible to bacterial contamination (Sinha et al., 2010). Consistent with our results, Orlofsky et al. 2016 showed no significant difference in the detection of fecal indicator bacteria on tomatoes irrigated with treated WW as compared with tomatoes irrigated with potable water. Farhadkhani et al. 2018, also detected a few of the selected pathogens in SWW and irrigated soils, but none of the tested plant samples were positive for the studied pathogens. Similar results were reported about the microbial quality of eggplant and tomatoes drip irrigated with treated WW (Cirelli et al., 2012).

Table 7: Microbiological load on crops

Sl. No.	Crop type	Total coliform (CFU/mL)		*E.Coli* (CFU/mL)		*Shigilla* (CFU/mL)		*Klebsiella* (CFU/mL)	
	Type of Water for irrigation	IRGW	NIGW	IRGW	NIGW	IRGW	NIGW	IRGW	NIGW
1.	Beetroot	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
2.	Tomato	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
3.	Spinach	200	480	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

(Note: N.D.- Not detectable. IRGW: Indirectly Recharged Groundwater; NIGW: Non-impacted Groundwater)

Conclusion:

The utilization of direct wastewater for irrigation poses many environmental problems such as soil quality deterioration due to the accumulation of salts, heavy metals, micro-pollutants and health risk due to undesirable microorganisms. This hampers its agricultural reuse in arid and semi-arid regions. To address these concerns, the present study introduces a recent approach that involves using indirectly recharged groundwater (GW) with secondary treated municipal wastewater (STW) for irrigation through a Soil Aquifer Treatment-based system (SAT). This method aims to mitigate freshwater scarcity in semi-arid regions. The outcomes of the study indicated no negative impact on soil properties when using indirectly recharged GW whereas a positive significant impact was reduced soil salinity in impacted areas. No microbial contamination in terms of pathogens was found on tested soil and crop samples. Hence, indirectly recharged GW using STW could be safely used as an alternative source for irrigation overcoming the concerns of heavy metals, micro-contaminants and pathogens associated with the direct use of partially treated or untreated mixed municipal WW for irrigation.

References:

1. Antil, R. S. (2012). Impact of sewage and industrial effluents on soil-plant health. *Industrial waste*, 53-54.
2. Abegunrin, T. P., Awe, G. O., Idowu, D. O., & Adejumobi, M. A. (2016). Impact of wastewater irrigation on soil physicochemical properties, growth and water use pattern of two indigenous vegetables in southwest Nigeria. *Catena*, *139*, 167-178.
3. Broszat, M., Nacke, H., Blasi, R., Siebe, C., Huebner, J., Daniel, R., & Grohmann, E. (2014). Wastewater irrigation increases the abundance of potentially harmful Gammaproteobacteria in soils in Mezquital Valley, Mexico. *Applied and environmental microbiology*, *80*(17), 5282-5291.
4. Bruto, M., Prigent-Combaret, C., Muller, D., & Moënne-Loccoz, Y. (2014). Analysis of genes contributing to plant-beneficial functions in plant growth-promoting rhizobacteria and related Proteobacteria. *Scientific reports*, *4*(1), 6261.
5. Cirelli, G. L., Consoli, S., Licciardello, F., Aiello, R., Giuffrida, F., & Leonardi, C. (2012). Treated municipal wastewater reuse in vegetable production. *Agricultural Water Management*, *104*, 163-170.
6. DeBruyn, J. M., Nixon, L. T., Fawaz, M. N., Johnson, A. M., & Radosevich, M. (2011). Global biogeography and quantitative seasonal dynamics of Gemmatimonadetes in soil. *Applied and environmental microbiology*, *77*(17), 6295-6300.
7. Edge, T. A., & Hill, S. (2007). Multiple lines of evidence to identify the sources of faecal pollution at a freshwater beach in Hamilton Harbour, Lake Ontario. *Water research*, *41*(16), 3585-3594.
8. Farhadkhani, M., Nikaeen, M., Yadegarfar, G., Hatamzadeh, M., Pourmohammadbagher, H., Sahbaei, Z., & Rahmani, H. R. (2018). Effects of irrigation with secondary treated wastewater on physicochemical and microbial properties of soil and produce safety in a semi-arid area. *Water research*, *144*, 356-364.
9. Fuerst, J. and Sagulenko, E. (2011). Beyond the bacterium: planctomycetes challenge our concepts of microbial structure and function. Journal Nature Reviews Microbiology, 9, 403-413
10. Government of India, Ministry of Agriculture & Farmers Welfare Department of Agriculture, Cooperation & Farmers Welfare, Directorate of Economics and Statistics (2017). https://www.soilhealth.dac.gov.in/
11. Ibekwe, A. M., Gonzalez-Rubio, A., & Suarez, D. L. (2018). Impact of treated wastewater for irrigation on soil microbial communities. *Science of the Total Environment*, *622*, 1603-1610.
12. Jeong, H., Kim, H., & Jang, T. (2016). Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea. *Water*, *8*(4), 169.
13. Kaur, R., Wani, S. P., Singh, A. K., & Lal, K. (2012, May). Wastewater production, treatment and use in India. In *National Report presented at the 2nd regional workshop on Safe Use of Wastewater in Agriculture* (pp. 1-13).
14. Keraita, B., Drechsel, P., & Konradsen, F. (2008). Perceptions of farmers on health risks and risk reduction measures in wastewater-irrigated urban vegetable farming in Ghana. *Journal of Risk Research*, *11*(8), 1047-1061.
15. Khan, A., Khan, S., Khan, M. A., Qamar, Z., & Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and

associated health risk: a review. *Environmental science and pollution research*, *22*, 13772-13799.
16. Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z., & Zhu, Y. G. (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental pollution*, *152*(3), 686-692.
17. Kielak, A. M., Cipriano, M. A., & Kuramae, E. E. (2016). Acidobacteria strains from subdivision 1 act as plant growth-promoting bacteria. *Archives of microbiology*, *198*, 987-993.
18. Kristanti, R. A., Ngu, W. J., Yuniarto, A., & Hadibarata, T. (2021). Rhizofiltration for removal of inorganic and organic pollutants in groundwater: a review. *Biointerafce Res. Appl. Chem*, *4*, 12326-12347.
19. Li, W., Zhang, Y., Mao, W., Wang, C., & Yin, S. (2020). Functional potential differences between Firmicutes and Proteobacteria in response to manure amendment in a reclaimed soil. *Canadian Journal of Microbiology*, *66*(12), 689-697.
20. Libutti, A., Gatta, G., Gagliardi, A., Vergine, P., Pollice, A., Beneduce, L., Disciglio, G. and Tarantino, E., (2018). Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. *Agricultural Water Management*, *196*, pp.1-14.
21. Malisorn, K., Chanchampa, S., Kanchanasin, P., & Tanasupawat, S. (2020). Identification and plant growth-promoting activities of proteobacteria isolated from root nodules and rhizospheric soils. *Current Applied Science and Technology*, 479-493.
22. Manisha, M., Verma, K., Ramesh, N., Anirudha, T.P., Santrupt, R.M., Das, R., Kumar, M.M., Chanakya, H.N., Rao, L., (2023). Socio-economic impact assessment of large-scale recycling of treated municipal wastewater for indirect groundwater recharge. Sci. Total Environ., 859, 160207.
23. Mehmood, A., Mirza, M.A., Choudhary, M.A., Kim, K.H., Raza, W., Raza, N., Lee, S.S., Zhang, M., Lee, J.H. and Sarfraz, M., (2019). Spatial distribution of heavy metals in crops in a wastewater irrigated zone and health risk assessment. *Environmental research*, *168*, pp.382-388.
24. Obeng, F. A., Gyasi, P. B., Olu-Taiwo, M., & Ayeh-Kumi, F. P. (2018). Microbial assessment of tomatoes (Lycopersicon esculentum) sold at some central markets in ghana. *BioMed research international*, *2018*.
25. Orlofsky, E., Bernstein, N., Sacks, M., Vonshak, A., Benami, M., Kundu, A., Maki, M., Smith, W., Wuertz, S., Shapiro, K. and Gillor, O., (2016). Comparable levels of microbial contamination in soil and on tomato crops after drip irrigation with treated wastewater or potable water. *Agriculture, ecosystems & environment*, *215*, pp.140-150.
26. Pansu, M., & Gautheyrou, J. (2006). of Soil Analysis.
27. Rezapour, S., Atashpaz, B., Moghaddam, S. S., & Damalas, C. A. (2019). Heavy metal bioavailability and accumulation in winter wheat (Triticum aestivum L.) irrigated with treated wastewater in calcareous soils. *Science of the Total Environment*, *656*, 261-269.
28. Shafiani, S., & Malik, A. (2003). Tolerance of pesticides and antibiotic resistance in bacteria isolated from wastewater-irrigated soil. *World Journal of Microbiology and Biotechnology*, *19*, 897-901.
29. Sharma, V., & Salwan, R. (2018). Biocontrol potential and applications of Actinobacteria in agriculture. In *New and future developments in microbial biotechnology and bioengineering* (pp. 93-108). Elsevier.

30. Sinha, N. K., Hui, Y. H., Evranuz, E. Ö., Siddiq, M., & Ahmed, J. (2010). *Handbook of vegetables and vegetable processing*. John Wiley & Sons.
31. Sou, M. Y., Mermoud, A., Yacouba, H., & Boivin, P. (2013). Impacts of irrigation with industrial treated wastewater on soil properties. *Geoderma, 200*, 31-39.
32. Subrahmanyan, V. (1932). Sewage Farming in India. *Current Science, 1*(6), 157-160.
33. USEPA (2002), United States Environmental Protection Agency. Method 1604: Total Coliforms and Escherichia coli in Water by MembraneFiltration Using a Simultaneous Detection Technique (MI Medium). U.S. Environmental Protection Agency. Office of Water (4303T) 1200 Pennsylvania Avenue, NW Washington, DC 20460. EPA-821-R-02-024; September 2002.
34. Ugwu, O. C., Chukwuezi, F. O., & Ozougwu, V. E. O. (2014). Microbial agents of tomato spoilage in Onitsha metropolis. *Advances in Biological Research, 8*(2), 87-93.
35. Yang, S., Feng, W., Wang, S., Chen, L., Zheng, X., Li, X., & Zhou, D. (2021). Farmland heavy metals can migrate to deep soil at a regional scale: A case study on a wastewater-irrigated area in China. *Environmental Pollution, 281*, 116977.

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08th of November 2023

To
The Chief Engineer,
Minor Irrigation and Ground Water Department (South)
Bangalore Karnataka

Dear Sir

Ref

1) AEE/MI&GWD Sub Varthur /K&C Valley/ 2023-24/224 dated 07-11-2023
2) "Environmental Impact Assessment of KC Valley Project", Agreement No 134/2019-20 dated 02/03/2020
3) Interim report submitted by CST-IISc dated 21-01-2022
4) No:AEE/MI&GWD Sub Varthur /K&C Valley/ 148/2023-24 dated 31-07-2023

With respect to the above reference, we would like submit the following

IISc team is monitoring/measuring heavy metals periodically in K & C valley project. Table 1 below lists the date/location of water sampling and the important findings. The drinking water specification IS 10500: 2012 lists 18 metals out of which 6 are listed as toxic heavy metals. In the secondary treated water from the STPs of K & C valley and Bellandur, all these 18 metals are well below the acceptable limits from the multiple samples collected between 2019 to 2022 (please note this **meets even the stringent drinking water standards**). Hence this water, when used for indirect recharge, is not expected to cause any heavy metal pollution of the underground water table.

Table 1: Heavy Metals Measured in K & C Valley Project

Sl No	Date of Sample	Location	Remarks	Details
1	10th Jan 2019	10 locations including K&C valley	The secondary treated water which is being pumped to Kolar from STP at K & C Valley and Bellandur does not	Annexure I

		STPs and Tanks in Cluster 1	contain any harmful heavy metals above the prescribed limit and even meets drinking water Standards IS 10500: 2012	
2	10th Jan 2020	All five inlets to Bellandur Lake and outlet of Bellandur Lake	Heavy metals even in untreated wastewater entering Bellandur lake from all five inlets and even the Bellandur lake outlet is within the prescribed limit even for drinking water Standards IS 10500: 2012. The wastewater undergoes anaerobic conditions during which all of them will precipitate out even if present.	Annexure -II
3	15th of March 2021	Raw sewage entering K&C valley STP and Secondary Treated water pumped to Kolar	The heavy metal concentrations in secondary treated water which is being pumped to Kolar from STP at K & C Valley and Bellandur are well below even the drinking water Standards IS 10500: 2012	Annexure -III
4	5th October 2021	DC point, Narasapura Tank, open well, borewell and Kalyani near Narsapura Tank	The secondary treated water which is being pumped to Kolar from STP at K & C Valley and Bellandur does not contain any harmful heavy metals above the prescribed limit as per drinking water Standards IS 10500: 2012 (meets even the drinking water standards) Even the groundwater in borewells, open wells and Kalyani near Narsapura Tank does not contain any harmful heavy metals above the prescribed limit as per drinking water Standards IS 10500: 2012	Annexure -IV
5	20th of July 2022	DC point and Lakshmisagar Tank Outlet	The secondary treated water which is being pumped to Kolar from STP at K & C Valley and Bellandur does not contain any harmful heavy metals above the prescribed limit as per drinking water Standards IS 10500: 2012 (meets even the drinking water standards)	Annexure -V

As can be seen from Table I, the secondary treated water which is being pumped to Kolar from STP at K & C Valley and Bellandur does not contain any harmful heavy metals above the prescribed limit **even as per drinking water Standards IS 10500: 2012.**

Also, IISc has clearly demonstrated that thermodynamically, any heavy metal will have the propensity to precipitate as sulphides and form insoluble salts very rapidly, thus rendering the wastewater free from heavy metals, which is published in Current Science Article, given here as Annexure VI.

Also, IISc has regularly published this data on absence of heavy metals in groundwater and surface water samples impacted by K&C valley project and secondary treated water being pumped to Kolar through various publication attached here as Annexure VII and Annexure VIII.

Sincerely

Dr. Lakshminarayana Rao
CST, IISc

Prof. H N Chanakya
CST IISc

Prof. M S Mohan Kumar
(Former Prof.) CE, IISc

1. Copy to Secretary, Minor Irrigation& Groundwater development Department, Government of Karnataka, Vikasa Soudha, Bangalore for information.
2. Copy to Superintending Engineer, Minor Irrigation Circle, Bangalore for information.
3. Copy to Executive Engineer, Minor Irrigation Division, Kolar for information and necessary action.
4. Copy to AEE MI subdivision Varthur for necessary action.

Annexure - I

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7th of March 2019

A note on STP secondary treated water quality of K and C Valley and Bellandur

Background This project is about supplying secondary treated domestic sewage water to tanks of Kolar for indirect recharge of underground water. In this project, secondary treated sewage water is directly picked up from the plant and passed on to pipe at K& C valley and Bellandur and thus the situation of getting mixed up with existing Lake waters at Bellandur does not arise. This is one of the unique projects where a Mega City (which is normally seen as guzzler of water and energy) becomes a source for indirect ground water recharge and irrigation in neighboring towns / villages and peri urban areas thus supporting their livelihood ecology / environment and other activities. There is a UN mandate on use of right quality of water for right purpose indicating necessity for minimal treatment which is enough for the purpose. Treated Water as it flows from one tank to the other, the quality of such waters will improve since it will be exposed to oxygenation and sunlight. Mixing with local catchment waters, the quality will only improve, if no local waste water flows in. Moisture build up will happen surrounding the tank areas which will help in agriculture. Need based, small quantity water could be treated to the drinking water standards

- In India, there are no water quality standards for such applications i.e., indirect recharge from secondary treated waters. However, based on the water quality testing that has been done as per the submitted report titled "Report of Secondary Treated Water Quality from K & C valley, Bellandur STP and tanks in Kolar", dated 21st Jan 2019 and the final report dated 7th of March 2019, the secondary treated water from K & C valley and Bellandur STP meets:
  - the water quality criteria for irrigation as per IS:11624-1986, BIS Standard.
  - the water meets the Class E criteria as per "DESIGNATED BEST USE CLASSIFICATION OF STREAMS', of CPCB, which is for Irrigation and industrial cooling.'

- In most of the cases, the Water Quality satisfies, Class D which is fit for Aquaculture as well
  - Based on the water analysis result presented as per the above said report, this secondary treated water from the K & C valley and Bellandur STP can be safely used for indirect recharge of underground water and Irrigation purposes.
- Water which is fit for irrigation purposes is certainly fit for indirect recharge of underground water.
- The drinking water specification IS 10500: 2012 lists 18 metals out of which 6 are listed as toxic heavy metals. In the secondary treated water from the STPs of K & C valley and Bellandur, all these 18 metals are well below the acceptable limits. Hence this water, when used for indirect recharge, is not expected to cause any heavy metal pollution of the underground water table.
- Heavy metals in the treated water from the treatment plant are well below the acceptable limits for drinking water and hence of no serious threat is likely to human / animal life from these heavy metals.
- During the indirect recharge, it is well understood that the water percolates slowly through the torturous pores through multilayers of the Mother Earth. During this process of slow percolation, it is well understood that the water quality improves even further as it trickles down through such soil layers.
- As the above observations are based on a single grab sample taken on 10th of Jan 2019, in order to get a better control of the system, it is suggested that periodic monitoring, lab testing, documentation and reporting mechanism needs to be implemented through any credible third-party observers.
- Several Institutes / research labs / regulatory authorities have tested the quality of secondary treated waters and have come with similar opinion that it meets the required standards.
- If need be, once the plant starts running, again, the quality of secondary treated waters could be ascertained by National Labs Institutes of high repute such as IISc and NEERI.

Lakshminarayana Rao
Date : 7th of March 2019

H N Chanakya
Date : 7th of March 2019

Report of Secondary Treated Water Quality from K & C valley, Bellandur STP and tanks in Kolar

1. INTRODUCTION

The Minor Irrigation Department has implemented a project for pumping secondary treated water from the STP at K &C Valley and Bellandur to fill 126 tanks in Kolar District. On 9th January 2019, the Minor Irrigation department approached IISc to sample the secondary treated water which is pumped to tanks in Kolar. On 10th of January 2019, IISc team undertook a water quality sampling campaign and have collected ten (10) water samples from various locations as listed in Table 1. The water quality is being accessed at IISc. IISc team of professors, consisting of Prof H N Chanakya and Dr Lakshminarayana Rao have analyzed the samples collected and a report is prepared. The details of the same are described below.

Table 1: Summary of water samples collected

Sl. No	Water Sampling Location	Sample Identification #
1	K & C valley STP - Before chlorine contact tank	1
2	K & C valley STP - After chlorine contact tank (Lift Point 1)	2
3	Bellandur STP after Chlorination tank (Life Point 2)	3
4	Discharge point Lakshmisagar Lake (first drop point into Kollar tanks)	4
5	Lakshmisagara waste weir (Outlet from Lakshmisagar lake)	5
6	Udapanahalli tank-1 (First lake downstream of Lakshmisagar lake)	6
7	Udapanahalli waste weir-2 (outlet from Udapanahalli Lake)	7
8	Narsapura tank	8
9	Doddavalabhi waste weir	9
10	Signahalli tank	10

2. WATER QUALITY OF SAMPLES COLLECTED

Table 2 lists water quality parameters analyzed of the water samples collected and Table 3 lists the test methods followed to analyze each parameter. Based on the results of the analysis the following conclusions are drawn and recommendations are made.

- Based on the water analysis, the water quality meets the water quality criteria for irrigation as per IS:11624-1986, BIS Standard (Annexure I).
- Based on the water analysis, as presented in Table 2, the water meets the Class E criteria as per "DESIGNATED BEST USE CLASSIFICATION OF STREAMS', of CPCB, which is for 'Irrigation and industrial cooling' (Annexure II). This water pumped to the tanks of Kolar can be safely used for Irrigation purposes.
- As India does not have any specific standards for indirect ground water recharge i.e., percolation through the soil strata and as recharged ground water is mostly used for irrigation purposes in Kolar, as indicated above, it meets the criteria for irrigation through ground water as the designated best use.
- In addition, the water quality of the all the water samples analyzed, for all the measured parameters as shown in Table 2, also meets a much stringent criteria as per the CPCB Inland surface water standards (Annexure I). The results indicate that the secondary treated water which is being pumped to Kolar from STP at K & C valley and Bellandur does not contain any harmful heavy metals above the prescribed limit.
- Also, the secondary treated water which is being pumped from STP at K & C valley and Bellandur i.e., sample 2,3 and 4 meet the Class D criteria as per "DESIGNATED BEST USE CLASSIFICATION OF STREAMS', of CPCB, which is for 'propagation of wild life and fisheries' (Annexure II).
- The above results are based on a single grab sample taken on 10th of Jan 2019. In order to get a better control of the system, it is suggested that periodic monitoring, lab analysis, documentation and reporting mechanism needs to be implemented.

Dr H N Chanakya Dr Lakshminarayana Rao

Date : 7th of March 2019

Table 2: Water Quality as on 10-01-19

Sl. No	Parameters	Unit	CPCB: Inland Surface water Standards	Water Quality Criteria					Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6	Sample #7	Sample #8	Sample #9	Sample #10
				A	B	C	D	E										
1.	Total Dissolved Solids	mg/L	-	-	-	-	-	-	480	414	426	471	450	428	424	332	305	376
2.	Turbidity	NTU	-	-	-	-	-	-	4.37	2.39	3.03	2.95	11.50	9.09	26.9	36.9	22.8	32.7
3.	Electrical Conductivity	µs/cm	-	-	-	-	-	2250	960	828	852	942	900	856	848	664	610	752
4.	Temperature	°C	shall not exceed 5°C above the receiving water temperature	-	-	-	-	-	23.5	24.6	24.9	23.2	24.8	23.7	24.2	23.9	24.1	24.5
5.	pH	-	5.5-9.0	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.0-8.5	8.6	7.7	7.8	8.0	8.4	8.7	9.0	9.2	8.9	8.5
6.	Particulate size of suspended solids	-	Shall pass 850 micron IS Sieve	-	-	-	-	-	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve	Passed 850 IS micron sieve

7.	Color	-	Colorless	-	-	-	-	-	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
8.	BOD for 5 days at 20°C	mg/l	30	2	3	3	-	-	6.2	3.6	3.8	5.9	2.6	2.9	6.2	3.7	3.2	6.9
9.	COD	mg/l	250	-	-	-	-	-	59.68	46.42	47.98	53.05	19.89	20.34	53.06	46.42	39.79	53.05
10.	Total Alkalinity as $CaCO_3$	mg/l	-	-	-	-	-	-	212	170	182	212	188	188	184	126	114	128
11.	Total Hardness as $CaCO_3$	mg/l	-	-	-	-	-	-	216	206	194	212	232	214	228	132	118	150
12.	Nitrate	mg/l	45	-	-	-	-	-	48.69	30.54	32.36	17.26	35.85	34.53	39.39	13.72	6.64	11.51
13.	Nitrite	mg/l	-	-	-	-	-	-	1.09	0.48	0.56	0.62	0.58	0.61	0.68	0.15	0.04	0.12
14.	Ammonical nitrogen (as N)	mg/l	50	-	-	-	-	-	0.942	0.673	0.598	0.582	0.320	0.293	0.208	0.188	0.165	0.219
15.	Free ammonia (as NH_3)	mg/l	5.0	-	-	-	-	-	3.797	0.432	0.491	0.661	0.942	2.242	1.739	2.035	1.168	0.773
16.	Free Ammonia (as N)	mg/l	-	-	-	-	1.2	-	3.12	0.355	0.404	0.544	0.775	1.844	1.431	1.674	0.961	0.636
17.	Iron (as Fe)	mg/l	3.0	-	-	-	-	-	0.354	0.363	0.321	0.358	0.299	0.251	0.549	0.355	0.199	0.307
18.	Manganese (as Mn)	mg/l	2.0	-	-	-	-	-	0.069	0.024	0.006	0.009	0.006	0.002	0.01	0.036	0.045	0.081
19.	Zinc (as Zn)	mg/l	5.0	-	-	-	-	-	bdl	bdl	0.028	bdl	0.002	0.104	bdl	bdl	bdl	bdl
20.	Cadmium (as Cd)	mg/l	2.0	-	-	-	-	-	0.00002	0.000057	bdl	bdl	bdl	bdl	0.003	0.000051	bdl	0.0005

21.	Lead (as Pb)	mg/l	0.1	-	-	-	-	-	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
22.	Total arsenic (as As)	mg/l	0.2	-	-	-	-	-	0.002	0.001	0.001	0.001	0.000774	0.0007	0.002	0.003	0.002	0.001
23.	Hexavalent Chromium (as Cr^{+6})	mg/l	0.1	-	-	-	-	-	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
24.	Total Chromium (as Cr)	mg/l	2.0	-	-	-	-	-	0.006	0.006	0.004	0.008	0.004	0.009	0.01	0.01	0.009	0.005
25.	Nickel (as Ni)	mg/l	3.0	-	-	-	-	-	0.029	0.028	0.024	0.028	0.023	0.018	0.029	0.014	0.011	0.01
26.	Copper (as Cu)	mg/l	3.0	-	-	-	-	-	0.002	0.001	0.000064	0.002	bdl	bdl	0.002	0.002	0.002	0.002
27.	Aluminium (as Al)	mg/l	-	-	-	-	-	-	0.036	0.109	0.02	0.121	0.025	0.012	0.375	0.261	0.086	0.077
28.	Barium (as Ba)	mg/l	-	-	-	-	-	-	0.044	0.045	0.01	0.048	0.003	0.011	0.059	0.048	0.046	0.039
29.	Boron (as B)	mg/l	-	-	-	-	-	2.0	0.019	0.021	0.037	0.022	0.018	0.019	0.022	0.025	0.026	0.02
30.	Calcium (as Ca)	mg/l	-	-	-	-	-	-	57.21	57.8	58.45	61.02	56.66	44.41	62.9	29.81	23.00	20.4
31.	Magnesium (as Mg)	mg/l	-	-	-	-	-	-	16.81	17.16	3.35	17.66	11.69	6.582	17.42	13.08	12.58	7.985
32.	Selenium (as Se)	mg/l	0.05	-	-	-	-	-	0.000673	0.000698	0.008	0.000665	0.001	0.008	0.000618	0.000642	0.000593	0.000460
33.	Silver (as Ag)	mg/l	-	-	-	-	-	-	0.000888	0.000429	0.000395	0.000634	0.000169	0.00005	0.000402	0.002	0.000498	0.000501
34.	Mercury (as Hg)	mg/l	0.01	-	-	-	-	-	0.002	0.00096	0.003	0.002	0.000478	0.002	0.000899	0.000334	0.000697	0.00019
35.	Molybdenum (as Mo)	mg/l	-	-	-	-	-	-	0.001	0.001	0.003	0.001	0.000413	0.001	0.001	0.002	0.002	0.001

36.	Sodium adsorption ratio	√(m mol/ l)	-	-	-	-	-	26.4	2.914	2.816	2.476	2.864	1.298	2.778	2.948	3.510	3.617	2.245
37.	RSC	me/l	-	-	-	-	-	-	0.66	1.5	0.2	1.01	0.65	0.45	1.32	0.25	0.2	0.47

*bdl= below detection limit

Table 3: Parameters analysed and Analysis methodology

Sl No.	Parameters	Method References
1.	Total Dissolved Solids	APHA 23rd Edition 2540-C
2.	Turbidity	APHA 23rd Edition 2130-B
3.	Conductivity	APHA 23rd Edition 2510-B
4.	pH	APHA 23rd Edition 4500-H^+, B
5.	BOD for 5 days at 20°C	APHA 23rd Edition 5210-B
6.	COD	APHA 23rd Edition 5220-C
7.	Total Alkalinity as $CaCO_3$	APHA 23rd Edition 2320-B
8.	Total Hardness as $CaCO_3$	APHA 23rd Edition 2340-C
9.	Nitrate	APHA 23rd Edition 4500-NO_3^-, E
10.	Nitrite	APHA 23rd Edition 4500-NO_2^-, B
11.	Ammonia-N	IS: 3025 (Part 34)- 2009
12.	Iron (as Fe)	APHA 23rd Edition 3125-B
13.	Manganese (as Mn)	APHA 23rd Edition 3125-B
14.	Zinc (as Zn)	APHA 23rd Edition 3125-B
15.	Cadmium (as Cd)	APHA 23rd Edition 3125-B
16.	Lead (as Pb)	APHA 23rd Edition 3125-B
17.	Total arsenic (as As)	APHA 23rd Edition 3125-B
18.	Total chromium (as Cr)	APHA 23rd Edition 3125-B
19.	Magnesium (as Mg)	APHA 23rd Edition 3125-B
20.	Nickel (as Ni)	APHA 23rd Edition 3125-B
21.	Copper (as Cu)	APHA 23rd Edition 3125-B
22.	Aluminium (as Al)	APHA 23rd Edition 3125-B
23.	Barium (as Ba)	APHA 23rd Edition 3125-B
24.	Boron (as B)	APHA 23rd Edition 3125-B
25.	Calcium (as Ca)	APHA 23rd Edition 3125-B
26.	Selenium (as Se)	APHA 23rd Edition 3125-B
27.	Silver (as Ag)	APHA 23rd Edition 3125-B
28.	Mercury (as Hg)	APHA 23rd Edition 3125-B
29.	Molybdenum (as Mo)	APHA 23rd Edition 3125-B
30.	Sodium (as Na)	APHA 23rd Edition 3125-B

ANNEXURE-1

IS : 11624 - 1986

Indian Standard

GUIDELINES FOR THE QUALITY OF IRRIGATION WATER

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 27 March 1986, after the draft finalized by the Irrigation Equipment and Systems Sectional Committee had been approved by the Agricultural and Food Products Division Council.

0.2 The quality of irrigation water is to be evaluated in terms of degree of harmful effects on soil properties with respect to the soluble salts it contains in different concentrations and crop yield. To evaluate the quality of irrigation water, this standard has been prepared as a guideline for advisory purposes.

0.3 In the preparation of this standard, considerable assistance has been derived from the Central Soil Salinity Research Institute, Karnal and Water Technology Centre, Indian Agricultural Research Institute, New Delhi.

0.4 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard prescribes the guidelines for assessing the quality of irrigation water.

2. TERMINOLOGY

2.1 For the purpose of this standard the definitions given in IS : 7022-1973† and IS : 11077-1984‡ shall apply.

*Rules for rounding off numerical values (*revised*).

†Glossary of terms relating to water, sewage, industrial effluents.

‡Glossary of terms on soil and water.

3. SUITABILITY CRITERIA

3.1 The suitability of an irrigation water depends upon several factors, such as, water quality, soil type, plant characteristics, irrigation method, drainage, climate and the local conditions. The integrated effect of these factors on the suitability of irrigation water (*SI*) can be expressed by the relationship given below:

$$SI = \int QSPCD$$

where

Q = quality of irrigation water, that is, total salt concentration, relative proportion of cations, etc;

S = soil type, texture, structure, permeability, fertility, calcium carbonate content, type of clay minerals and initial level of salinity and alkalinity before irrigation;

P = salt tolerance characteristics of the crop to be grown, its variety and growth stage;

C = climate, that is, total rainfall, its distribution and evaporation characteristics; and

D = drainage conditions, depth of water table, nature of soil profile, presence of hard pan or lime concentration and management practices.

3.1.1 These factors act interactively such that a single suitable criteria is hard to be adopted for widely varying conditions. However, a general broad guideline has been developed here.

3.2 Besides these factors, the presence of potassium and nitrate ions in water, is favourable for crop growth, as water of more salinity can be used in presence of these ions. In a particular climate, all the factors enumerated in 3.1, are likely to vary and interact either positively or negatively in relation to salt accumulation and degree of harmful effect on soil properties and crop growth.

4. WATER QUALITY CRITERIA FOR IRRIGATION

4.1 The following chemical properties shall be considered for developing water quality criteria for irrigation:

a) Total salt concentration,

b) Sodium adsorption ratio,

c) Residual sodium carbonate or bicarbonate ion concentration, and

d) Boron content.

4.1.1 *Total Salt Concentration* — It is expressed as the electrical conductivity (EC). In relation to hazardous effects of the total salt concentration, the irrigation water can be classified into four major groups as given in Table 1.

TABLE 1 WATER QUALITY RATING BASED ON THE TOTAL SALT CONCENTRATION

Sl. No.	Class	Range of EC (Micromhos/cm)
(1)	(2)	(3)
i)	Low	Below 1 500
ii)	Medium	1 500-3 000
iii)	High	3 000-6 000
iv)	Very high	Above 6 000

4.1.2 *Sodium Adsorption Ratio* (*SAR*) — shall be calculated from the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}}$$

where

SAR = sodium adsorption ratio $\sqrt{(\text{millimole/litre})}$

Na = sodium ion concentration, me/l

Ca = calcium ion concentration, me/l

Mg = magnesium ion concentration, me/l

NOTE — me/l = milliequivalent/litre.

In relation to the hazardous effects of sodium adsorption ratio, the irrigation water quality rating is given in Table 2.

TABLE 2 WATER QUALITY RATING BASED ON SODIUM ADSORPTION RATIO

Sl. No.	Class	SAR Range $\sqrt{(\text{millimole/litre})}$
(1)	(2)	(3)
i)	Low	Below 10
ii)	Medium	10-18
iii)	High	18-26
iv)	Very high	Above 26

4.1.3 Residual sodium carbonate (RSC) shall be determined by the equation:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

where

RSC = residual sodium carbonate (me/l),
CO_3^{2-} = carbonate ion concentration (me/l),
HCO_3^- = bicarbonate ion concentration (me/l),
Ca^{2+} = calcium ion concentration (me/l), and
Mg^{2+} = magnesium ion concentration (me/l).

NOTE — me/l = milliequivalent/litre.

In relation to the hazardous effects of high bicarbonate ion concentration expressed as residual sodium carbonate, the irrigation water quality rating is given in Table 3.

TABLE 3 WATER QUALITY RATING BASED ON RESIDUAL SODIUM CARBONATE

SL No.	CLASS	RSC RANGE (me/l)
(1)	(2)	(3)
i)	Low	Below 1·5
ii)	Medium	1·5-3·0
iii)	High	3·0-6·0
iv)	Very high	Above 6·0

4.1.4 *Boron Content* — Boron, though a nutrient, becomes toxic if present in water beyond a particular level. In relation to boron toxicity, the irrigation water quality rating is given in Table 4.

TABLE 4 WATER QUALITY RATING BASED ON BORON CONTENT

SL No.	CLASS	BORON (ppm)
(1)	(2)	(3)
i)	Low	Below 1·0
ii)	Medium	1·0-2·0
iii)	High	2·0-4·0
iv)	Very high	Above 4·0

4.2 Though all the chemical characteristics have been classified separately, they are present in each irrigation water, and the chemical characteristics of a particular class of water is independent of the chemical characteristics of different classes of water. For example, a water of high EC may or may not have high SAR or RSC or boron. These chemical characteristics interact with each other and cause hazardous effects on soil properties and crop growth.

5. WATER QUALITY RATING IN RELATION TO SOIL TYPE AND CROP TOLERANCE TO SALTS

5.1 Keeping in view the soil types and quality of ground water, the upper permissible limit of electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and boron content for the semi-tolerant and tolerant crops are given in Table 5, while tolerance of crops to salinity, sodicity and boron are given in Table 6.

TABLE 5 SUITABILITY OF IRRIGATION WATER FOR SEMI-TOLERANT AND TOLERANT CROPS IN DIFFERENT SOIL TYPES

Sl No.	Soil Textural Group	Upper Permissible Limit of							
		Salinity		Sodicity				Boron	
		EC (micromhos/cm)		SAR $\sqrt{\text{(milli mole/l)}}$		RSC (me/l)		B (ppm)	
		S.T.*	T.†	S.T.*	T.†	S.T.*	T.†	S.T.*	T.†
i)	*Above 30 Percent Clay* Sandy clay, clay loam, silty clay loam, silty clay, clay	1 500	2 000	10	15	2	3	2	2
ii)	*20-30 Percent Clay* Sandy clay loam, loam, silty loam	4 000	6 000	15	20	3	4	2	3
iii)	*10-20 Percent Clay* Sandy loam, loam, silty loam	6 000	8 000	20	25	4	5	2	3
iv)	*Below 10 Percent Clay* Sand, loamy sand, sandy loam, silty loam, silt	8 000	10 000	25	30	5	6	1	2

NOTE — The use of waters of 4 000 micromhos/cm EC and above be confined to winter season crops only. They should not be used during the summer season. Even during emergencies not more than one or two protective irrigations be given to the Kharif season crops.

*Semi-tolerant crops.
†Tolerant crops.

5.1.1 These limits are for specific conditions where the rainfall is below 600 mm/annum, no other source of water is available, drainage and water table is not a serious limitation. Presence of nitrate in water and gypsum in soil is favourable. Similarly, sulphate : chloride and calcium : magnesium ratio above 2·0 in water is also beneficial.

TABLE 6 TOLERANCE OF FIELD AND VEGETABLE CROPS TO SALINITY, SODICITY AND BORON

(Clause 5.1)

Crops	Salinity		Sodicity		Boron	
	S. T.*	T.†	S.T.*	T.†	S.T.*	T.†
Wheat	X		X		X	
Barley		X	X		X	
Cotton	X		X		X	
Oil seed crops	X		X		X	
Maize	X		X		X	
Jowar	X		X		X	
Bajra	X		X		X	
Rice	X		X		X	
Sugarcane	X		X		X	
Sugar beet		X		X		X
Tomato	X		X		X	
Cauliflower	X		X			X
Cabbage	X		X			X
Onion	X		X			X
Carrot	X		X			X
Radish	X		X		X	
Grasses	X			X		X
Berseem	X		X		X	

*Semi-tolerant.
†Tolerant.

ANNEXURE-2

[1][SCHEDULE – VI]

(See rule 3A)

GENERAL STANDARDS FOR DISCHARGE OF ENVIRONMENTAL POLLUTANTS PART-A : EFFLUENTS

S. No.	Parameter	Standards			
		Inland surface water	Public Sewers	Land for irrigation	Marine coastal areas
1	2	3			
		(a)	(b)	(c)	(d)
1.	Colour and odour	See 6 of Annexure-I	–	See 6 of Annexure -I	See 6 of Annexure-I
2.	Suspended solids mg/l, Max.	100	600	200	(a) For process waste water-100 (b) For cooling water effluent 10 percent above total suspended matter of influent.
3.	Particulate size of suspended solids	Shall pass 850 micron IS Sieve	–	–	(a) Floatable solids, max. 3 mm. (b) Settleable solids, max. 850 microns.
[2]4.	***	*	–	***	–
5.	pH Value	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
6.	Temperature	shall not exceed 5°C above the receiving water temperature	–	–	shall not exceed 5°C above the receiving water temperature

1 Schedule VI inserted by Rule 2(d) of the Environment (Protection) Second Amendment Rules, 1993 notified vide G.S.R. 422(E) dated 19.05.1993, published in the Gazette No. 174 dated 19.05.1993.

2 Omitted by Rule 2(d)(i) of the Environment (Protection) Third Amendment Rules, 1993 vide Notification No.G.S.R. 801(E), dated 31.12.1993

ANNEXURE-3 (Contd)

S. No.	Parameter	Standards			
		Inland surface water	Public Sewers	Land for irrigation	Marine coastal areas
1	2	3			
		(a)	(b)	(c)	(d)
7.	Oil and grease mg/l Max.	10	20	10	20
8.	Total residual chlorin mg/l Max.	1.0	--	–	1.0
9.	Ammonical nitrogen (as N), mg/l Max.	50	50	–	50
10.	Total Kjeldahl Nitrogen (as NH_3) mg/l, Max.	100	–	–	100
11.	Free ammonia (as NH_3) mg/l, Max.	5.0	–	–	5.0
12.	Biochemical Oxygen demand [1][3 days at 27°C] mg/l max.	30	350	100	100
13.	Chemical Oxygen Demand, mg/l, max.	250	–	--	250
14.	Arsenic (as As), mg/l, max.	0.2	0.2	0.2	0.2
15.	Mercury (as Hg), mg/l, Max.	0.01	0.01	–	0.01
16.	Lead (as Pb) mg/l, Max.	0.1	1.0	--	2.0
17.	Cadmium (as Cd) mg/l, Max.	2.0	1.0	–	2.0
18.	Hexavalent Chromium (as Cr+6), mg/l max.	0.1	2.0	--	1.0

[1] Substituted by Rule2 of the Environment (Protection) Amendment Rules, 1996 notified by G.S.R.176, dated 2.4.1996 may be read as BOD (3 days at 27°C) wherever BOD 5 days 20°C occurred.

ANNEXURE-3 (Contd)

S. No.	Parameter	Standards			
		Inland surface water	Public Sewers	Land for irrigation	Marine coastal areas
1	2	3			
		(a)	(b)	(c)	(d)
19.	Total chromium (as Cr.) mg/l, Max.	2.0	2.0	–	2.0
20.	Copper (as Cu) mg/l, Max.	3.0	3.0	–	3.0
21.	Zinc (As Zn.) mg/l, Max.	5.0	15	–	15
22.	Selenium (as Se.) mg/l, Max.	0.05	0.05	–	0.05
23.	Nickel (as Ni) mg/l, Max.	3.0	3.0	–	5.0
[1]24.	* * *	*	*	*	*
[1]25.	* * *	*	*	*	*
[1]26.	* * *	*	*	*	*
27.	Cyanide (as CN) mg/l Max.	0.2	2.0	0.2	0.2
[1]28.	* * *	*	*	*	*
29.	Fluoride (as F) mg/l Max.	2.0	15	–	15
30.	Dissolved Phosphates (as P), mg/l Max.	5.0	–	–	–
[2]31.	* * *	*	*	*	*
32.	Sulphide (as S) mg/l Max.	2.0	–	–	5.0
33.	Phenolic compounds (as C_6H_5OH) mg/l, Max.	1.0	5.0	–	5.0

[1] Omitted by Rule 2(d)(i) of the Environment (Protection) Third Amendment Rules, 1993 vide Notification No.G.S.R.801(E), dated 31.12.1993

ANNEXURE-3 (Contd)

S. No.	Parameter	Standards			
		Inland surface water	Public Sewers	Land for irrigation	Marine coastal areas
1	2	3			
		(a)	(b)	(c)	(d)
34.	Radioactive materials :				
	(a) Alpha emitter micro curie/ml.	10^{-7}	10^{-7}	10^{-8}	10^{-7}
	(b) Beta emitter micro curie/ml.	10^{-6}	10^{-6}	10^{-7}	10^{-6}
35.	Bio-assay test	90% survival of fish after 96 hours in 100% effluent	90% survival of fish after 96 hours in 100% effluent	90% survival of fish after 96 hours in 100% effluent	90% survival of fish after 96 hours in 100% effluent
36.	Manganese (as Mn)	2 mg/l	2 mg/l	–	2 mg/l
37.	Iron (as Fe)	3 mg/l	3 mg/l	–	3 mg/l
38.	Vanadium (as V)	0.2 mg/l	0.2 mg/l	–	0.2 mg/l
39.	Nitrate Nitrogen	10 mg/l	–	–	20 mg/l
[1]40.	* * *	*	*	*	*

[1] Omitted by Rule 2(d)(i) of the Environment (Protection) Third Amendment Rules, 1993 vide Notification No. G.S.R. 801(E) dated 31.12.1993

Annexure - II

Table 1: Heavy metal and mineral concentration in lake inlets

Parameters	Unit	IS 10500	Kempapura	Koramangala	Iblur	HAL	Agara	Bellandur Outlet
Al	ppm	0.2	0.01048	0.003652	0.01268	0.006181	0.01076	0.129
Cr		0.1	0.000417	0.000703	0.000615	0.000919	0.001615	0.005
Mn		2	0.2035	0.152	0.0953	0.04143	0.1951	0.161
Fe		3	0.06484	0.07809	0.05479	0.09566	0.1055	0.769
Ni		3	0.001086	0.002069	0.002018	0.0015	0.002526	0.005
Co			0.01603	0.02118	0.02123	0.01602	0.0234	0.0219
Cu		3	BDL	0.002456	0.001668	0.001669	0.01075	0.003
Zn		5	BDL	0.002657	0.07303	BDL	0.002489	0.045
As		0.2	0.000057	0.000058	0.000055	0.000059	0.000055	0.00094
Mo		0.07	0.001367	0.000993	0.001378	0.00062	0.001112	0.001
Ag		0.1	BDL	0.000007	0.000001	BDL	0.00002	BDL
Cd		2	BDL	0.000045	BDL	BDL	0.000019	0.005
Mg			58.3	62.72	54.47	15.14	55.64	45.6
K			33.65	44.7	36.63	6.45	38.82	
Ca			34.04	34.22	41.47	19.66	30.23	33.51
Hg		0.01	0.0002	BDL	BDL	0.002	BDL	BDL
Pb		0.1	BDL	0.0002	BDL	0.0007	BDL	0.001

BDL means below below detectable limit which is 1×10^{-6} mg/l.

Annexure - III

Date of Sampling : 15th of March 2021

Table of Heavy Metals

Summary of heavy metals analysis.

S.No.	Metals, metalloids, and heavy metals	IS 10500 (mg/l)	Raw sewage (mg/l)	Secondary treated wastewater(mg/l)
1	Iron (Fe)	3	0.40	0.36
2	Manganese (Mn)	2	0.16	0.02
3	Zinc (Zn)	5	0.02	BDL
4	Cadmium (Cd)	2	BDL	BDL
5	Lead (Pb)	0.1	BDL	BDL
6	Arsenic (As)	0.2	0.001	BDL
7	Chromium (Cr^{+3})	0.1	0.004	0.001
8	Nickel (Ni)	3	0.02	< 0.1
9	Copper (Cu)	3	0.00005	0.028
10	Aluminium (Al)	0.2	0.03	0.00
11	Barium (Ba)	0.7	0.01	BDL
12	Boron (B)	0.5	0.04	0.045
13	Selenium (Se)	0.01	0.008	0.021
14	Silver (Ag)	0.1	0.00041	BDL
15	Mercury (Hg)	0.001	0.004	BDL
16	Molybdenum (Mo)	0.07	0.003	BDL

Note: **BDL is below the detection limit of 1×10^{-6} mg/l.**

Annexure - IV

Date of Sampling: 5th of October 2021

Table : Summary of Heavy Metal Analysis of the DC Point Lakshmisagar and Narsapura Tank

Standard Name	Iron (Fe) mg/L	Manganese (Mn) mg/L	Cadmium (Cd) mg/L	Lead (Pb) mg/L	Chromium (Cr) mg/L	Nickel (Ni) mg/L	Copper (Cu) mg/L	Mercury (Hg) mg/L	Aluminium (Al) mg/L
IS10500	3	2	2	0.1	0.1	3	3	0.002	0.2
DC Point	0.26	Bdl	Bdl	Bdl	0	0	0.002	0.001	0
Narsapura Tank	0.2	Bdl	Bdl	Bdl	0	0	0.001	0	0
Borewell	0.23	Bdl	0	Bdl	Bdl	0	0.051	0	0
Open well	0.47	Bdl	0	Bdl	Bdl	Bdl	0.016	0.03	Bdl
Kalyani	0.25	Bdl	0	Bdl	Bdl	Bdl	0.01	0	Bdl

Annexure - V

Date of Sampling 20th July 2022

Table: Summary of Heavy Metal Analysis of the DC point and Lakshmisagar tank outlet

Sl. No.	Parameters	IS 10500 (mg/L) (BIS 10500, 2012)	Secondary treated wastewater at DC point (mg/L)	Lakshmisagara tank outlet (LT) (mg/L)
1	Iron (Fe)	3	0.36 ± 0.02	0.26 ± 0.001
2	Manganese (Mn)	2	0.02 ± 0	BDL ± 0
3	Zinc (Zn)	5	BDL ± 0	BDL ± 0
4	Cadmium (Cd)	2	BDL ± 0	BDL ± 0
5	Lead (Pb)	0.1	BDL ± 0	BDL ± 0
6	Arsenic (As)	0.2	0.001 ± 0	0.001 ± 0
7	Chromium (Cr^{+5})	0.1	<0.1 ± 0	<0.1 ± 0
8	Nickel (Ni)	3	0.028 ± 0	0 ± 0
9	Copper (Cu)	3	0.00 ± 0	0 ± 0
10	Aluminium (Al)	0.2	BDL ± 0	0 ± 0
11	Barium (Ba)	0.7	0.045 ± 0	0.01 ± 0
12	Boron (B)	0.5	0.021 ± 0	0.001 ± 0
13	Selenium (Se)	0.01	BDL ± 0	BDL ± 0
14	Silver (Ag)	0.1	BDL ± 0	BDL ± 0
15	Mercury (Hg)	0.001	BDL ± 0	BDL ± 0
16	Molybdenum (Mo)	0.07	0.001 ± 0	BDL ± 0
BDL is Below Detectable Limit which is is 1×10^{-6} mg/l				

Annexure - VI

Fate of heavy metals in sewage and polluted water bodies

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There is a major knowledge gap and a multifarious problem involving metal chemistry, physical interactions of metals, microbiology, aerobic and anaerobic processes in understanding the precipitation of heavy metals in sewage and polluted water bodies. This study focuses on determining the most feasible metal-salt that can be formed using standard Gibbs free energy change for each possible reaction of all the heavy metals in wastewater. Solubility limits of all possible metal salts are computed. It is shown that even in the short anaerobic stage, any heavy metal will have the propensity to precipitate as sulphides and form insoluble salts, thus rendering the wastewater free from heavy metals. The measured heavy metal concentration in treated wastewater from Bangalore's K–C Valley and Bellandur sewage treatment plants is presented as a validation of the theory.

Keywords: Anaerobic digestion, heavy metals, precipitation, solubility limit, wastewater.

Origin of heavy metals in urban sewage and threat to lakes

THE ever increasing sewage generation from urbanization and consequent threats to water resources are important concerns to sustainable development. Majority of the world's population now lives in the cities[1–6]. Nearly one-third of the Indian population is urbanized and many states are expected to have more than half of their population in cities by 2021 (ref. 7). Most cities have little wastewater infrastructure[8]. Cities have become large sinks for water and epicentres for wastewater (sewage). Cities usurp water from hundreds of kilometres away while the rainwater collection tanks have become receptacles of sewage. When untreated sewage flows under anaerobic conditions, most of the metals present are precipitated and deposited as a heavy metal (HM)-rich sludge[9].

Cities in the Deccan Plateau have always aligned their sewerage systems along with the natural contours of land and water basins. These water bodies have become perpetually filled with sewage. For example, Varthur and Bellandur lakes of Bengaluru, Musi in Hyderabad and River Cooum in Chennai receive large volumes of urban sewage. As cities are industrialized, storm water, sewage and industrial effluents became mixed and flow as common wastewater. For a significant period, industries in Bengaluru such as battery reconditioning, electroplating and paint shops have released effluents bearing HMs into sewage[10]. It is unclear what happens to these HMs in sewage streams. The present study answers this question using both thermodynamic potential and solubility limitations.

By definition, metallic elements and metalloids having atomic density >5 g/cm^3 are termed as 'heavy metals'[11,12]; for example, As (5.75 g/cm^3), Zn (7.14 g/cm^3), Cr (7.15 g/cm^3), Mn (7.30 g/cm^3), Fe (7.87 g/cm^3), Cd (8.69 g/cm^3), Co (8.86 g/cm^3), Ni (8.90 g/cm^3), Cu (8.96 g/cm^3), Mo (10.2 g/cm^3), Ag (10.5 g/cm^3), Pb (11.30 g/cm^3) and Hg (13.53 g/cm^3). Selenium having an atomic density of 4.8 g/cm^3 is also included in this list given its toxic nature. All these HMs, except silver, are toxic. Although the dominant material of sewage is consumed food, several other household chemicals also enter it. Food contains only insignificant levels of HMs and over 99% of the digestible organic food matter is absorbed by humans. Rejects are further digested as sewage decomposes rapidly, anaerobically or aerobically, leaving behind these unused HMs. Sewage, especially as settled sludge, is known to accumulate these HMs and is often considered as an environmental threat[12,13].

The Environmental Protection rules of 1986 have specified the discharge standards for 10 HMs, namely As, Hg, Pb, Cd, Cr^{+6}, Cr, Cu, Zn, Se and Ni[14]. A few recent reports claim that these HMs are present in amounts higher than the permissible limits in urban sewage[15–21]. Bioaccumulation of HMs in the riverine/lacustrine systems and the risk of reusing sewage water on health, agriculture and environment have been reported. For example, according to a study on crops and soils receiving sewage from Bellandur, Byramangala, Nagavara and Varthur tanks in Bengaluru, the average HM concentration of water from these water bodies ranged from 0.014 to 0.039 mg/l for Cd, 0.039 to 0.075 mg/l for Pb, 0.120 to 0.311 mg/l for Cr and 0.027 to 0.042 mg/l for Ni[22]. The concentration of Pb and Ni was within the safe limits of 0.5 mg/l and 0.2 mg/l respectively, according to the guidelines for irrigation water[22]. Nevertheless, it is not clear how these levels, well above typical solubility

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levels of their respective sulphides, have been reported from sewage under chronic anaerobic conditions.

Several studies have indicated that under anaerobic conditions, in the presence of hydrogen sulphide (H_2S), HMs present in the sewage tend to rapidly precipitate or bind to the sludge, forming metal sulphides which precipitate out of the water given their low water solubility[23–25]. Being highly insoluble, they need to be resolubilized into forms that plants can take up and such a process is unlikely to take place with sewage under normal conditions.

This study evaluates the fate of HMs in urban sewage. A thermodynamic study based on standard Gibbs free energy change (ΔG^0) was conducted to determine which metal-salts will be formed spontaneously under anaerobic conditions. The ΔG^0 values were calculated for each possible reaction of all the HMs with other anions and neutral species. The most spontaneous reactions based on the lowest ΔG^0 values were determined to arrive at the most feasible product salt formed. Based on the solubility limits of the salts formed, this study shows that HMs present in the sewage will turn almost immediately into insoluble sulphides which will precipitate out of the water, thus rendering the wastewater free from HMs.

Water chemistry of heavy metals in urban sewage

Unlike the tanks filled by run-off and drying off during summer, sewage-fed water bodies remain continuously filled for decades and show macrophyte infestation[26]. Within a few minutes of discharge of sewage, it gets mixed with a larger sewage flow and rapid digestion of the organics begin. This absorbs all dissolved oxygen and the sewage first becomes anoxic and almost immediately anaerobic. Under anaerobic conditions hydrogen (H_2) is generated and sulphate-reducing bacteria converts the sulphur in organic matter and products of fermentations to H_2S and HCO_3^- (eq. (1))[27]. Nitrates and sulphates are used in place of oxygen, releasing H_2, CO_2, NH_3 and more H_2S. The redox potential measured against a standard hydrogen electrode falls below –200 mV. CO_2 is reduced to CH_4 using H_2 by methanogenic bacteria. The redox potential drops up to –400 mV, a stage at which few metals can remain in soluble form. The H_2S produced (~ –50 mV) reacts with the metals present to form insoluble metal sulphides that subsequently precipitate (eq. (2))[28]. This precipitation can be correlated with the Kipp's apparatus. This is used to generate H_2S, which when bubbled through metallic salt solutions of either Pb, Ag or Cu forms a black precipitate almost immediately, even as H_2S, was brought near the salt solution[29]. H_2S readily reacts with metal ions to give corresponding metal sulphides.

$$2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^- \quad \text{(in the presence of anaerobic bacteria)}, \qquad (1)$$

where $-CH_2O$ represents organic matter.

$$M^{2+} + H_2S \leftrightarrow MS(s)\downarrow + 2H^+, \qquad (2)$$

where M includes metals such as Fe, Cu, Zn, Ni, Cd, etc.

The metal sulphides formed because of anaerobic conditions have very low solubility in water over a wide pH range[30]. These HM-sulphide salts bind to the sludge which gradually settles as sludge or silt at the lake bottom.

Standard Gibbs free energy change for heavy metal salts in urban sewage

Table 1 shows the standard Gibbs free energy (ΔG^0) of all possible reactions for 13 HMs[31,32]. As shown in table, for each metal, ΔG^0 for the formation of metal sulphide is the lowest, indicating that metal sulphide formation is more spontaneous/favourable compared to all other metallic salt formations, namely metal hydroxides, chlorides, fluorides, phosphates, chromates, bromates, bromides, carbonates, metal iodates, metal iodides, nitrates and metal sulphates. This result matches with the earlier studies confirming formation of metal sulphides in sewage[23–25] and as explained by eq. (2)[28]. Also, this result agrees with earlier studies which have reported that sulphide precipitates are thermodynamically the most copious product in the inorganic fraction under anaerobic conditions and HMs will precipitate as sulphides to form insoluble salts[23]. These data strongly indicate that propensity of metal-sulphide formation in wastewater is the highest and will occur rapidly, if not instantly.

Solubility of heavy metal salts in urban sewage

Solubility limits of salts in a liquid can be determined by calculating the solubility product (K_{sp}) at a given pH and temperature[33]. Table 1 lists the K_{sp} and solubility of various metal salts at 298.15 K. As shown in the table, the solubility of sulphides is the least at room temperature (e.g. for HgS solubility at 298.15 K is 1.47×10^{-11} mg/l), indicating that the metal sulphides are least soluble in water. Metal ligands are formed based on Lewis's acid–base interactions. Hard ions (such as Al^{3+}, Ba^{2+}, Be^{2+}, Co^{3+}, Cr^{3+}) have highest affinity towards ions of hard bases (such as OH^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-) to form ionic complexes and are less toxic in nature. Soft acid ions (such as Ag^+, Cd^{2+}, Cu^+, Hg^{2+}) have highest affinity towards ions of soft base (such as HS^-, S^{2-}, CN^-) to form covalent complexes and are toxic in nature. The tendency of metals to form solid phases, such as sulphides, is related to their hard and soft (Lewis) acids and base qualities[34]. Each metal has a specific affinity with each anionic system and the order of precipitation is dependent

Table 1. Standard Gibbs free energy change of the reaction, selected solubility product constants and solubility of heavy metals at 298.15 K, 1 bar (at zero ionic strength)[31,32]

Reaction	$\Delta G^0_{298.15\,K,\,1\,bar}$ (kJ/mol)	K_{sp} at 298.15 K	Solubility (mg/l) at 298.15 K
Arsenic (As)			
$2As^{3+} + 3S^{2-} \rightarrow As_2S_3$	–422.3	2.1×10^{-22}	5.17×10^{-5} at 291.15 K
$As^{3+} + 3F^- \rightarrow AsF_3$	64.1	–	–
$As^{3+} + 3I^- \rightarrow AsI_3$	97.3	–	–
$As^{3+} + 3Cl^- \rightarrow AsCl_3$	136.1	–	–
Zinc (Zn)			
$Zn^{2+} + S^{2-} \rightarrow ZnS$	–140	1.2×10^{-23} at 291.15 K	3.38×10^{-7} at 291.15 K
$Zn^{2+} + 2OH^- \rightarrow Zn(OH)_2$	–92	3×10^{-17}	0.195
$Zn^{2+} + CO_3^{2-} \rightarrow ZnCO_3$	–56.6	1.46×10^{-10}	1.515
$Zn^{2+} + 2F^- \rightarrow ZnF_2$	–8.6	3.04×10^{-2}	2.03×10^4
$Zn^{2+} + 2NO_3^- \rightarrow Zn(NO_3)_2$	0.1	–	5.46×10^5
$Zn^{2+} + SO_4^{2-} \rightarrow ZnSO_4$	20.1	–	3.66×10^5
$Zn^{2+} + 2Cl^- \rightarrow ZnCl_2$	40.1	–	8.03×10^5
$Zn^{2+} + 2I^- \rightarrow ZnI_2$	41.3	–	8.14×10^5
$Zn^{2+} + 2Br^- \rightarrow ZnBr_2$	43	–	8.3×10^5
Chromium (Cr)			
$Cr^{2+} + S^{2-} \rightarrow CrS$	–305.8	Insoluble	Insoluble–
$Cr^{3+} + 3F^- \rightarrow CrF_3$	–57.1	6.6×10^{-11}	1.36×10^2
$Cr^{3+} + 3Cl^- \rightarrow CrCl_3$	102	–	5.9×10^5 at 293.15 K (for $CrCl_3 \cdot 6H_2O$)
Manganese (Mn)			
$Mn^{3+} + S^{2-} \rightarrow MnS$	–76.1	1.4×10^{-15} at 291.15 K	3.26×10^{-3} at 291.15 K
$Mn^{2+} + 2Cl^- \rightarrow MnCl_2$	–0.3	–	4.36×10^5
$Mn^{2+} + 2NO_3^- \rightarrow Mn(NO_3)_2$	–0.3	–	6.17×10^5
$Mn^{2+} + SO_4^{2-} \rightarrow MnSO_4$	–0.2	–	3.89×10^5
$Mn^{2+} + 2Br^- \rightarrow MnBr_2$	26.9	–	6.019×10^5
$Mn^{2+} + 2F^- \rightarrow MnF_2$	36.7	–	1.01×10^4
Iron (Fe)			
$Fe^{2+} + S^{2-} \rightarrow FeS$	–107.3	3.7×10^{-19} at 291.15 K	5.35×10^{-5} at 291.15 K
$Fe^{2+} + SO_4^{2-} \rightarrow FeSO_4$	0	–	2.28×10^5
$Fe^{3+} + 3NO_3^- \rightarrow Fe(NO_3)_3$	0.3	–	4.657×10^5
Cadmium (Cd)			
$Cd^{2+} + S^{2-} \rightarrow CdS$	–164.7	3.6×10^{-29} at 291.15 K	8.67×10^{-10} at 291.15 K
$Cd^{2+} + 2OH^- \rightarrow Cd(OH)_2$	–81.6	7.2×10^{-15}	1.781
$Cd^{2+} + 2I^- \rightarrow CdI_2$	–20.6	–	4.63×10^5
$Cd^{2+} + 2F^- \rightarrow CdF_2$	–12.5	6.44×10^{-3}	1.76×10^4
$Cd^{2+} + 2Br^- \rightarrow CdBr_2$	–10.7	–	5.34×10^5
$Cd^{2+} + 2Cl^- \rightarrow CdCl_2$	–3.9	–	5.46×10^5
$Cd^{2+} + SO_4^{2-} \rightarrow CdSO_4$	–0.6	–	4.34×10^5
$Cd^{2+} + 2NO_3^- \rightarrow Cd(NO_3)_2$	0.1	–	6.1×10^5
Cobalt (Co)			
$Co^{2+} + S^{2-} \rightarrow CoS$	–114.2	3.0×10^{-26} at 291.15 K	1.04×10^{-8} at 291.15 K
$Co^{2+} + 2OH^- \rightarrow Co(OH)_2$	–85.5	5.92×10^{-15}	1.059
$Co^{2+} + 2F^- \rightarrow CoF_2$	–35.2	–	1.4×10^4
$Co^{2+} + SO_4^{2-} \rightarrow CoSO_4$	–0.2	–	2.77×10^5
$Co^{2+} + 2I^- \rightarrow CoI_2$	–0.1	–	6.699×10^5
$Co^{2+} + 2NO_3^- \rightarrow Co(NO_3)_2$	0.1	–	5.08×10^5
$Co^{2+} + 2Cl^- \rightarrow CoCl_2$	0.1	–	3.59×10^5
Nickel (Ni)			
$Ni^{2+} + S^{2-} \rightarrow NiS$	–119.7	1.4×10^{-24} at 291.15 K	1.07×10^{-7} at 291.15 K
$Ni^{2+} + 2OH^- \rightarrow Ni(OH)_2$	–87.2	5.48×10^{-16}	0.478
$Ni^{2+} + 2F^- \rightarrow NiF_2$	–0.9	–	2.5×10^4
$Ni^{2+} + 2NO_3^- \rightarrow Ni(NO_3)_2$	–0.3	–	4.98×10^5
$Ni^{2+} + SO_4^{2-} \rightarrow NiSO_4$	–0.2	–	2.88×10^5
$Ni^{2+} + 2I^- \rightarrow NiI_2$	–0.2	–	6.069×10^5
$Ni^{2+} + 2Cl^- \rightarrow NiCl_2$	49	–	4.03×10^5

(Contd)

Table 1. (*Contd*)

Reaction	$\Delta G^0_{298.15\,K,\,1\,bar}$ (kJ/mol)	K_{sp} at 298.15 K	Solubility (mg/l) at 298.15 K
Copper (Cu)			
$Cu^{2+} + S^{2-} \rightarrow CuS$	–204.9	8.5×10^{-45} at 291.15 K	8.81×10^{-18} at 291.15 K
$Cu^{+} + I^{-} \rightarrow CuI$	–67.9	1.27×10^{-12}	0.215
$Cu^{+} + Br^{-} \rightarrow CuBr$	–46.8	6.27×10^{-9}	1.136×10^{1}
$Cu^{+} + Cl^{-} \rightarrow CuCl$	–38.7	1.72×10^{-7}	4.105×10^{1}
$Cu^{2+} + 2NO_3^{-} \rightarrow Cu(NO_3)_2$	0.1	–	5.92×10^{5}
$Cu^{2+} + SO_4^{2-} \rightarrow CuSO_4$	12.8	–	1.8×10^{5}
Molybdenum (Mo)			
$Mo^{4+} + S^{2-} \rightarrow MoS_2$	–388.95	2.2×10^{-56}	1.9×10^{-23}
Silver (Ag)			
$2Ag^{+} + S^{2-} \rightarrow Ag_2S$	–280.7	6×10^{-30}	2.84×10^{-5}
$Ag^{+} + I^{-} \rightarrow AgI$	–91.7	8.52×10^{-17}	0.002
$Ag^{+} + Br^{-} \rightarrow AgBr$	–70	5.35×10^{-13}	0.137
$2Ag^{+} + CrO_4^{2-} \rightarrow Ag_2CrO_4$	–68.2	1.12×10^{-12}	2.17×10^{1}
$2Ag^{+} + CO_3^{2-} \rightarrow Ag_2CO_3$	–63.2	8.46×10^{-12}	3.539×10^{1}
$Ag^{+} + Cl^{-} \rightarrow AgCl$	–55.7	1.77×10^{-10}	1.907
$Ag^{+} + BrO_3^{-} \rightarrow AgBrO_3$	–24.4	5.38×10^{-5}	1.729×10^{3}
$Ag^{+} + NO_3^{-} \rightarrow AgNO_3$	0.8	–	7.01×10^{5}
Lead (Pb)			
$Pb^{2+} + S^{2-} \rightarrow PbS$	–160.1	3.4×10^{-28} at 291.15 K	4.41×10^{-9} at 291.15 K
$Pb^{2+} + CO_3^{2-} \rightarrow PbCO_3$	–73.3	7.40×10^{-14}	0.073
$Pb^{2+} + 2I^{-} \rightarrow PbI_2$	–46	9.8×10^{-9}	6.215×10^{2}
$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$	–44.1	2.53×10^{-8}	4.824×10^{2}
$Pb^{2+} + 2F^{-} \rightarrow PbF_2$	–35.1	3.3×10^{-8}	4.95×10^{2}
$Pb^{2+} + 2Br^{-} \rightarrow PbBr_2$	–29.5	6.6×10^{-6}	4.336×10^{3}
$Pb^{2+} + 2Cl^{-} \rightarrow PbCl_2$	–27.3	1.7×10^{-5}	4.504×10^{3}
$Pb^{2+} + 2NO_3^{-} \rightarrow Pb(NO_3)_2$	0.1	–	3.738×10^{5}
Mercury (Hg)			
$Hg^{2+} + S^{2-} \rightarrow HgS$ (red)	–300.8	4×10^{-33}	1.47×10^{-11}
$Hg^{2+} + 2I^{-} \rightarrow HgI_2$	–162.9	2.9×10^{-29}	8.79×10^{-5}
$Hg_2^{2+} + 2Br^{-} \rightarrow Hg_2Br_2$	–126.6	6.40×10^{-23}	0.014
$Hg^{2+} + 2Br^{-} \rightarrow HgBr_2$	–109.5	–	6.1×10^{3}
$Hg_2^{2+} + 2Cl^{-} \rightarrow Hg_2Cl_2$	–101.8	1.43×10^{-18}	0.335
$Hg_2^{2+} + CO_3^{2-} \rightarrow Hg_2CO_3$	–93.8	3.6×10^{-17}	0.003
$Hg_2^{2+} + SO_4^{2-} \rightarrow Hg_2SO_4$	–34.8	6.5×10^{-7}	2.71×10^{3}

on the different K_{sp} values. Lower K_{sp} indicates lower solubility of the salt. In addition, metal sulphides are amphoteric and only slightly soluble in water[35]. The solubility data in Table 1 suggest that sulphide salts are water-insoluble, and form most stable precipitates under anaerobic conditions[34].

Another aspect that plays an important role in HM chemistry is pH. Figures 1 and 2 show the solubility of various metal salts in water at different pH values[37]. As shown in figures for all HMs, their solubility decreases with pH. Under anaerobic conditions, the following processes are known to increase the pH of wastewater above 8, from its initial value of 6.8–8.3, i.e. consumption of volatile fatty acids by methanogens and reduction of sulphate/sulphite to sulphides by sulphate reducing bacteria[36]. Under this pH condition, the metal sulphides of Zn, Cu, Ni, Cd, Fe, Mn, Hg and Ag are less soluble and more likely to form insoluble precipitates[26].

Under anaerobic conditions, the HMs are known to speciate and shift towards the solid phase, leading to lower concentrations in the liquid phase. The percentage of metals in the liquid phase represents only 0.5–4 of their total concentrations[25], whereas the remaining 99.5–96 shifts towards solid precipitate.

These data show that HMs that enter the wastewater systems which become anaerobic during their transport along waste streams, tend to form metal sulphides which rapidly precipitate out due to their low solubility.

Water quality and heavy metal concentration in urban sewage treatment plants

To validate the above theory, the treated wastewater from K–C Valley and Bellandur sewage treatment plant (STPs) were analysed, which have anaerobic digestion as part of their treatment process. Table 2 lists the discharge water quality from these STPs and compares it with the CPCB inland surface water discharge standards. The concentration of metals was determined by inductively coupled

Table 2. Water quality of sewage treatment plant as on 10 January 2019

Parameter	CPCB: inland surface water standards	K–C Valley STP	Bellandur STP
Temperature	Shall not exceed 5°C above the receiving water temperature	24.6	24.9
pH	5.5–9.0	7.7	7.8
Iron (as Fe; mg/l)	3.0	0.363	0.321
Manganese (as Mn; mg/l)	2.0	0.024	0.006
Zinc (as Zn; mg/l)	5.0	BDL	0.028
Cadmium (as Cd; mg/l)	2.0	0.000057	BDL
Lead (as Pb; mg/l)	0.1	BDL	BDL
Total arsenic (as As; mg/l)	0.2	0.001	0.001
Hexavalent chromium (as Cr + 6; mg/l)	0.1	<0.1	<0.1
Total chromium (as Cr; mg/l)	2.0	0.006	0.004
Nickel (as Ni; mg/l)	3.0	0.028	0.024
Copper (as Cu; mg/l)	3.0	0.001	0.000064
Aluminium (as Al; mg/l)	–	0.109	0.02
Barium (as Ba; mg/l)	–	0.045	0.01
Boron (as B; mg/l)	–	0.021	0.037
Calcium (as Ca; mg/l)	–	57.8	58.45
Magnesium (as Mg; mg/l)	–	17.16	3.35
Selenium (as Se; mg/l)	0.05	0.000698	0.008
Silver (as Ag; mg/l)	–	0.000429	0.000395
Mercury (as Hg; mg/l)	0.01	0.00096	0.003
Molybdenum (as Mo; mg/l)	–	0.001	0.003

BDL, Below detection limit of 1×10^{-12} mg/l.

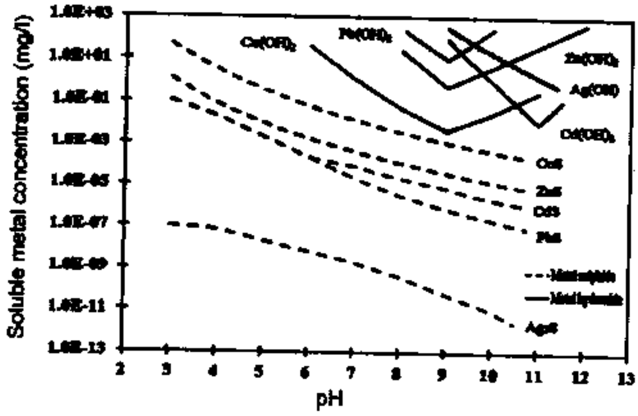

Figure 1. Solubilities of metal hydroxides and sulphides as a function of pH[37].

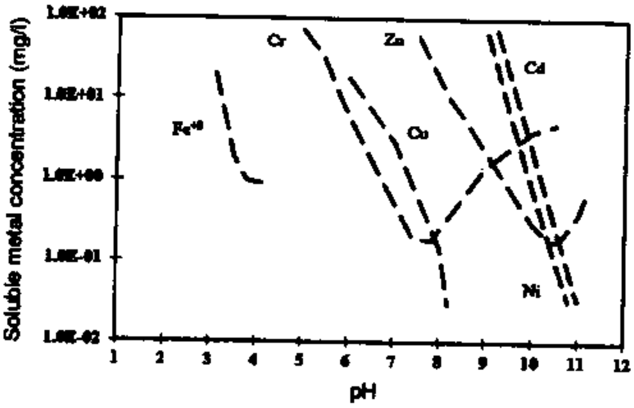

Figure 2. Metal solubilities as a function of pH[37].

plasma–mass spectrometry (ICP–MS) after filtering the samples using 0.45 μm membrane filter and acidifying them in 2% nitric acid matrix, according to the APHA[38]. The results indicate that HMs in the secondary treated water that has undergone anaerobic treatment are well below the discharge limits. Table 2 shows that the treated wastewater does not contain any harmful HMs above the prescribed limits, which provides evidence for the above theory of HM-sulphide formation and solubility in sewage systems.

Conclusion

The relative content of HMs tends to accumulate in urban sewage when organic matter content is sequentially digested in the food chain and often, storm water, sewage and industrial effluents become mixed. Occasionally, small amounts of industrial effluents entering fugitively into sewage-dominant wastewaters pose a serious challenge to the reuse of treated wastewater. The sewage systems under tropical climatic conditions undergo rapid anaerobic digestion leading to precipitation of HMs as metal sulphides. Metal sulphide precipitates are thermodynamically the most copious product in the inorganic fraction of wastewater under anaerobic conditions. It is therefore an important condition that sewage flow is maintained under typical anaerobic conditions, atleast for a few hours, to ensure that HMs if any, are allowed to form insoluble precipitates thus rendering the wastewater free from HMs. This process makes the sewage more appropriate for further treatment before it is released back to the environment.

1. Gross, M., The urbanisation of our species. *Curr. Biol.*, 2016, **26**, R1205–R1225.
2. Kim, Y. H. and Baik, J. J., Spatial and temporal structure of the urban heat island in Seoul. *J. Appl. Meteorol. Climatol.*, 2005, **44**, 591–605.
3. Ganesh, S. P. S. *et al.*, Decentralized treatment and recycling of greywater from a school in rural India. *J. Water Proc. Eng.*, 2020, **38**, 101695.
4. Reshma, M., Kumar, M. and Rao, L., CFD multiphase simulation of oxygen transfer from diffused aeration system in synthetic wastewater. *J. Water Process Eng.*, 2021, **40**, 101920.
5. Priyanka, J., Raj, A. V., Connelly, S., Yeluripati, J., Richards, S., Rao, L. and Tamburini, M., Evaluating the performance of planted and unplanted HSSF-constructed wetlands: a case study from southern India. *Ecol. Eng.*, 2021, **162**, 106170.
6. Samia, R. *et al.*, Sustainable water resources through harvesting rainwater and the effectiveness of a low-cost water treatment. *J. Environ. Manage.*, 2021, **286**, 112223.
7. Grimm, N. B. *et al.*, Global change and the ecology of cities. *Science*, 2008, **319**, 756–760.
8. Jain, M., Contemporary urbanization as unregulated growth in India: the story of census towns. *Cities*, 2018, **73**, 117–127.
9. Carrondo, M. J. T., Lester, J. N., Perry, R. and Stoveland, S., Analysis of heavy metals in Sewage Sludge, Sewages and Final Effluent. Final report to the Department of the Environment for contracts, Government of the United Kingdom, 1978, DGR/480/66.
10. Ogheneroбor, B. A., Ohiobor, G. O. and Olaolu, T. B., Heavy metal pollutants in wastewater effluents: sources, effects and remediation. *Adv. Biosci. Bioeng.*, 2014, **2**(4), 37–43.
11. Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. and Sutton, D. J., Heavy metal toxicity and the environment. *Mol. Clin. Environ. Toxicol.*, 2012, **3**, 133–164.
12. Duffus, J. H., 'Heavy metals' – a meaningless term? *Pure App. Chem.*, 2002, **74**(5), 793–807.
13. Gupta, A., Rai, D. K., Pandey, R. S. and Sharma, B., Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environ. Monit. Assess.*, 2008, **157**, 1–4.
14. GoI, The Environment (Protection) Rules, Ministry of Environment, Government of India, 1986.
15. Shivashankara, G., Ranga, P., Ramalingaiah, K. and Rao, M., Characteristics of bulk precipitation in industrial area of Bangalore City. *Indian J. Environ. Health*, 1999, **41**, 229–238.
16. Singh, A., Sharma, R. K., Agrawal, M. and Marshall, F. M., Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. *Food Chem. Toxicol.*, 2010, **48**(2), 611–619.
17. Singh, K. P., Mohan, D., Sinha, S. and Dalwani, R., Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area. *Chemosphere*, 2004, **55**(2), 227–255.
18. Lokeshwari, H. and Chandrappa, G. T., Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation. *Curr. Sci.*, 2006, **91**(5), 622–627.
19. Dheri, G. S., Brar, M. S. and Malhi, S. S., Heavy-metal concentration of sewage-contaminated water and its impact on underground water, soil and crop plants in alluvial soils of northwestern India. *Commun. Soil Sci. Plant Anal.*, 2007, **38**(9–10), 1353–1370.
20. Parashar, P. and Prasad, F. M., Study of heavy metal accumulation in sewage irrigated vegetables in different regions of Agra District, India. *J. Soil Sci.*, 2013, **3**, 1–8.
21. KC Valley project: IISc report warns of heavy metal content in treated water. *Econ. Times*, September 2018.
22. Varalakshmi, L. R. and Ganeshamurthy, A. N., Heavy metal contamination of water bodies, soils and vegetables in peri-urban areas: a case study in Bengaluru. *J. Hortic. Sci.*, 2012, **7**(1), 62–67.
23. Callander, I. J. and Barford, J. P., Precipitation, chelation, and the availability of metals as nutrients in anaerobic digestion. II. Applications. *Biotechnol. Bioeng.*, 1983, **25**(8), 1959–1972.
24. Kiran, G., Kannan, P. and Das, G., Heavy metal removal by sulfate reduction using anaerobic sludge biomass from a wastewater treatment plant. In International Conference on Hydrology and Watershed Management, India, 2014.
25. Roussel, J., Metal behaviour in anaerobic sludge digesters supplemented with trace nutrients. Ph.D. thesis, The University of Birmingham, UK, 2012.
26. Durga, M., Hoysall, C. and Ramachandra, T. V., Assessment of treatment capabilities of Varthur Lake, Bangalore, India. *Int. J. Environ. Technol. Manage.*, 2011, **143**, 84–102.
27. Bratkova, S., Angeloy, A., Nikolova, K., Loukanov A. and Plochey, S., Removal of Cu, Fe, Ni and Zn ions from waters with microbial produced hydrogen sulfide, *Annu. Univ. Mining Geol. 'St. Ivan Rilski'*, 2011, **54**, 175–180.
28. Aynsley, E. E. and Campbell, A. W., The laboratory preparation of hydrogen sulphide: a historical survey. *J. Chem. Edu.*, 1958, **35**(7), 347–349.
29. Cioabla, A. E., Ionel, I., Dumitrel, G. A. and Popescu, F., Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues. *Biotechnol. Biofuels*, 2012, **5**, 39.
30. Morse, J. W. and Luther, G. W., Chemical influences on trace metal–sulfide interactions in anoxic sediments. *Geochim. Cosmochim. Acta*, 1920, **63**, 3373–3378.
31. Haynes, W. M., *Handbook of Chemistry and Physics*, 95th edn, CRC Press, Boca Raton, Florida, USA, 2014.
32. Green, D. W. and Southard, M. Z., *Perry's Chemical Engineers' Handbook*, 9th edn, McGraw-Hill Education, New York, USA, 2019.
33. Olaniran, A., Balgobind, A. and Pillay, B., Bioavailability of heavy metals in soil: impact on microbial biodegradation of organic compounds and possible improvement strategies, *Int. J. Mol. Sci.*, 2013, **14**(5), 10197–10228.
34. Lewis, A. E., Review of metal sulphide precipitation. *Hydrometallurgy*, 2010, **104**(2), 222–234.
35. Richardson, H. W., *Handbook of Copper Compounds and Applications*, 1st edn, CRC Press, Boca Raton, Florida, USA, 1997, pp. 273–275.
36. Anderson, G. K. and Yang, G., pH control in anaerobic treatment of industrial wastewater. *J. Environ. Eng.*, 1992, **118**(4), 551–567.
37. Stinson, M. K., Control and treatment technology for the metal finishing industry: sulphide precipitation. Technical report prepared for United States Environmental Protection Agency, 1980, 625/8-80-003.
38. Rice, E. W., Baird, R. B. and Eaton, A. D., *Standard Methods for Examination of Water and Wastewater*, 23rd edn, American Public Health Association, 2017, 3125-B.

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Annexure - VII

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Socio-economic impact assessment of large-scale recycling of treated municipal wastewater for indirect groundwater recharge

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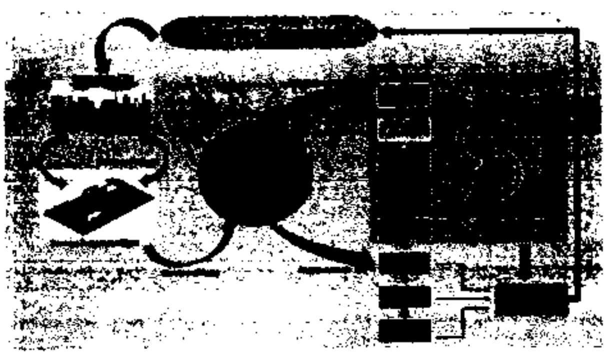
HIGHLIGHTS

- Large-scale recycling of treated wastewater for indirect groundwater recharge.
- Significant impact in the agricultural sector and socio-economic status.
- Enhancement in livestock, milk production, women's employment, and income.
- Contributed to the transition towards the circular economy in water sector.
- Need of the hour: Encouraging planning and management of wastewater reuse.

GRAPHICAL ABSTRACT



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ABSTRACT

Reusing treated wastewater is an emerging solution to address freshwater scarcity, and surface water contamination faced worldwide. A unique large-scale wastewater recycling project was implemented to replenish groundwater by filling secondary treated wastewater (STW) into existing irrigation tanks in severely drought-hit areas of the Kolar districts of Southern India. This study quantifies the socio-economic impacts of this large-scale indirect groundwater recharge scheme. The changes in areas receiving STW i.e., impacted areas and those areas which did not receive STW i.e., non-impacted areas was studied. Also, pre and post recycling changes were quantified in the Kolar district. The results show that surface water quality meets India's most stringent treated wastewater discharge standards prescribed by the Hon'ble National Green Tribunal. Due to these recycling efforts, significant improvements in groundwater level and quality were found. It was observed that there was a noticeable difference in agricultural cropping areas, seasons, patterns, and production between impacted and non-impacted areas. Post-recycling, farmers tended to cultivate cash and water-intensive crops over less water-intensive crops. During the post-recycling period, livestock and milk production also increased, and in impacted areas, it was significantly higher. Post-recycling, fish production increased and land prices per hectare increased by 118 % in impacted areas. The farmer's net income under flowers and vegetable farming increased by 202 % and 150 % respectively in impacted areas compared to non-impacted

Abbreviations: APHA, American Public Health Association; ARB, Antibiotic Resistance Bacteria; BOD, Biological oxygen demand; CGWB, Central ground water board; COD, Chemical oxygen demand; DEIAA, District Level Environment Impact Assessment Authority; DO, Dissolved oxygen; EC, Electric conductivity; ESRI, Environmental Systems Research Institute; GoK, Government of Karnataka; GW, Groundwater; ICPMS, Inductively coupled plasma-mass-spectrometry; IS, Indian Standard; K&C, Koramangala and Challaghatta; LCMS, Liquid chromatography–mass spectrometry; MI & GW, Minor Irrigation and Groundwater; MIC, Minimum inhibitory concentrations; PCPP, Pharmaceutical and personal care products; PPP, Public-private partnership; SAR, Sodium absorption rate; STP, Sewage treatment plant; STW, Secondary treated wastewater; TN, Total nitrogen; TSS, Total Suspended Solids.

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areas. Furthermore, this project contributes to a circular economy transition in the water sector, which has economic, environmental, social, and cultural benefits. A key recommendation from the outcomes of the study is to draft and implement a policy that encourages the reuse of recycled water for groundwater recharge which in turn will improve the agro-economic system and food security.

1. Introduction

The world is facing challenges to manage severe water crises because of various factors such as population growth, rapid urbanization, rural electrification, industrialization, climate change, and irresponsible use of natural resources (Okello et al., 2015; Shan et al., 2020). This has prompted the policymakers to consider treated wastewater as a sustainable source of water supply (Okello et al., 2015; Shan et al., 2020). India is the largest extractor of groundwater (GW) in the world, and GW is primarily used for agricultural needs, followed by domestic and industrial consumption (World Bank, 2012; Suhag, 2016). India extracts more GW than China and the United States combined (World Bank, 2010; Chindarkar and Grafton, 2019). India does not only suffer from GW scarcity, but contamination of ground and surface water has also become a matter of high concern (Biswas and Hartley, 2017; Dangar et al., 2021).

The declining level of India's GW gained the attention of multiple stakeholders including policymakers, scientists, academia, national and international institutions (Bera et al., 2022). This has initiated exploring innovative, sustainable, affordable, and safe solutions for water management that contribute to improve the GW table (Bera et al., 2022). The development and expansion of wastewater treatment and reuse have the high potential to sustainably develop water ecosystems, improve socio-economic status, positively contribute to the food-water-energy cycle, and build a circular economy (Jhansi and Mishra, 2013; Sathaiah and Chandrasekaran, 2020; Kesari et al., 2021). In various countries, treated wastewater is considered an efficient and safe additional water resource and is used to mitigate water scarcity through recharging GW table. For instance, Israel (Icekson-Tal et al., 2003), Egypt (Aly Gondia et al., 2021), Kuwait (Aleisa, 2019), Spain (Jodar-Abellan et al., 2019), and Mexico (Mazari-Hiriart et al., 2008) have pioneered the technology to treat >90 % of wastewater and reuse it mainly for agricultural irrigation. Jordan (WHO, 2006), Singapore (Tortajada and Bindal, 2020), and Australia (ARMCAN et al., 2000) have set the standard/ guidelines to reuse treated wastewater for indirect and direct GW recharge. In Singapore recycled wastewater now meets 40 % of Singapore's water demand (Kog, 2020) whereas in Australia GW recharge initiative is fulfilling 4 % of the country's integrated water supply scheme to increase the security of urban water (Dillon and Arshad, 2016). Table 1 represents the status of these treated wastewater reuse efforts.

The practice of using untreated or partially treated wastewater for agricultural irrigation has also been historically prevalent in India (Minhas et al., 2022). But India has not taken any large-scale initiative to reuse treated wastewater for different purposes and indirect GW recharge. The National Environmental Engineering Research Institute (NEERI) in Nagpur, India conducted a pilot study to reuse treated municipal wastewater for indirect GW recharge by implementing the soil aquifer treatment (SAT) method (NEERI, 2015). The SAT refers to the artificial recharge or infiltration of wastewater through the vadose (unsaturated) zone to recharge the underlying aquifers (Essandoh et al., 2011). Few other studies with the same objective and methods were carried out in Ahmedabad and Chennai to assess the potential of SAT. However, there are no reports that reveal full-fledged implementation from anywhere in India (Deepa and Krishnaveni, 2012; Packialakshmi et al., 2015). Recently, the National Geophysical Research Institute of India implemented a program for indirect GW recharge through managed aquifer recharge. Percolation tanks were built through community participation to store rainwater (Nandan et al., 2021).

A review of these works reveals major gaps in the quantification of the socio-economic benefits of wastewater recycling projects which is the objective of this study. Large-scale recycling of secondary treated municipal wastewater (STW) was initiated in March 2018, in the Southern Indian city of Bengaluru, which currently generates about 1480 million litres per day (MLD) of STW. Under a project titled "Koramangala-Challaghatta Valley (K&C) project", nearly 440 MLD of STW from Bengaluru is being used for

Table 1
Treated wastewater reuse in different countries.

Country	Project name	% of Domestic wastewater treated and reused	Treatment method	Purpose/benefit
Israel (Kanarek and Michail, 1996; Icekson-Tal et al., 2003)	The Dan Region Reclamation Project	90 % Reuse- 69 %	Secondary, biological, and tertiary: soil aquifer treatment	60 %: Agricultural irrigation;10 %: environmental firefighting; increasing river flow; groundwater recharge.
Mexico (World Bank, 2018)	Atotonilco wastewater treatment project	60 % Reuse-46 %	Primary, secondary and biological	Agriculture irrigation (>90,000 ha land); urban landscaping. park development, domestic use, groundwater recharge.
Egypt (Aly Gondia et al., 2021)	Part of Sinai Peninsula Development Program	60 % Reuse-44 %	Primary, secondary and disinfection	Agricultural; horticulture; forest irrigation; urban landscaping; reduce pollutants discharged into the Nile River. Treated sludge (biosolids) used as fertilizer
Singapore (Djamel et al., 2019; Tortajada and Bindal, 2020)	Changi Water Reclamation project is one of the largest and most advanced reclamation facilities in the world (NEWater).	80 % Reuse-54 %	A four-stage treatment process: conventional, micro-filtration, reverse osmosis, and UV treatment	Industrial purposes; domestic uses; irrigation; recharge local aquifers; drinking water supplies to 5.7 million people.
Kuwait (Abusam and Shahalam, 2013; Aleisa, 2019)	–	75 % Reuse-58 %	Ultrafiltration through reverse osmosis tertiary treatment: sand filtration and chlorination	Agricultural irrigation (19 %); golf courses; community gardens; airports; governmental headquarters; landscapes on major highways and the new campus of Kuwait university.

indirect GW recharge in severe drought-hit neighbouring areas of Bengaluru, i.e., Kolar districts. Kolar, a neighbouring district of Bengaluru, had turned dry due to minimal or no rain for the last 10 years (CGWB, 2016). The GW resources in the Kolar district were categorized as "over-exploited" and this resulted in the depletion of the GW table in the district (DEIAA, 2020). The DEIAA, 2020 report indicates that the GW table in the affected area was ~350–450 m from ground level. The persistent drought condition due to minimal rainfall and GW deficiency adversely impacted land use & irrigating areas, cropping pattern & productivity, socio-economic status, and migration of people to Bengaluru in search of employment (Ballukraya, 1997; Ramaiah et al., 2017; Garg et al., 2020). The focus of this study is to quantify the socio-economic impact of large-scale recycling of STW for indirect GW recharge. Specifically, the objectives were i) to determine the impact of indirect groundwater recharge on surface water quality, GW level, and GW quality, and ii) to determine the impact on socio-economic development and sustainability.

The socio-economic impact was quantified by comparing the socio-economic changes in the impacted locations (i.e., regions influenced by STW) with that of the non-impacted locations (i.e., regions not influenced by STW) of Kolar and a comparative study was also carried out between pre and post recycling period of the impacted areas.

2. Material and methods

2.1. Study area and the K&C valley project

Kolar district is in a semi-arid, drought-prone region located in the southeast of Karnataka state and covers an area of 3990 km^2 with a population of 1.54 million. The major source of livelihood in the district is agriculture and associated activities (Kolar district profile, 2009; Nagaraj et al., 2003). Agriculture is mostly dependent on rainwater, minor irrigation tanks, and borewells. Kolar district anciently had around 3000 man-made surface reservoirs/tanks which were the highest in Karnataka (GoK (Government of Karnataka), 2016). The tank water was used for various purposes, such as controlled irrigation, domestic and livestock needs, and also provided GW recharge (Lars Engberg-Pedersen, 2011). With little or no rains over the last 10 years, numerous tanks and borewells had gone dry and the GW table declined at alarming levels due to over-exploitation (CGWB, 2016). The depth of irrigation borehole wells had reached ~250–300 m from the surface (Garg et al., 2020).

The K&C valley project is a large-scale (~440 MLD), indirect GW recharge project initiated in March 2018, by the Minor Irrigation and Groundwater Development (MI&GW) Department of the Government of Karnataka to provide relief to these persistent drought-hit areas in the Kolar districts. The project aims to fill existing tanks using STW coming from the two sets of STPs located in Bengaluru. This project covers five Taluks (sub-unit of a District) in Kolar district namely Kolar, Srinivasapura, Mulabagilu, Bangarapet, and Malur. As of July 2022, a total of 137 tanks have been filled. The distribution of STW to existing tanks is divided into 12 clusters in order to track the supply, maintenance, and impact. A key map of the project is provided in Fig. A.1 in appendix A. The project is designed/implemented by ensuring safety and awareness among the public, for ex: a bi-lingual (Kannada & English) board is placed near each tank that reads- "This water is meant for indirect groundwater recharge only". This project was designed to provide irrigation water to ~24,000 ha of land, enhance water security for Kolar, re-establish plant and animal biodiversity, revive the rural economy, and ultimately improve the quality of life.

2.2. Data collection

2.2.1. Water quality analysis of secondary treated water and surface tank

The STW samples from STP and water samples from surface tanks receiving STW were collected and analysed following the standard methods (APHA, 2005). The test results were compared with the most stringent surface water discharge standards as prescribed by India's The Hon'ble National Green Tribunal (NGT) (shown in Table 3), which focuses on the discharge of treated wastewater into water bodies as well as for land disposal/applications (NGT, 2019). All the eight water quality parameters as per the Hon'ble NGT standard namely pH, biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), and ammonical nitrogen (NH_4-N), phosphate phosphorus (PO_4-P) and faecal coliform were monitored. In addition to the above eight parameters, the STW and surface water quality were also compared with the Central Polution Control Board (CPCB, 2013) standards for dissolved oxygen (DO), electric conductivity (EC), sodium absorption ratio (SAR), and Boron (B) (Table 3). All the water samples were tested in triplicates and average values along with standard deviation are presented as avg. ± std. dev. A detailed analysis for heavy metals was also carried out for the raw sewage entering STPs and STW using ICPMS (Quadrupole ICPM- Thermo X series II). An attempt was also made out to analyse pharmaceutical and personal care products (PCPPs) in the STW using LCMS (Dionex Ultimate 3000 (Thermo), micro-LC equipped with C18, 150 × 4.6 mm, 5 μm reversed phase column. Preliminary determination on antibiotic resistance bacteria (ARBs) was carried out using Ezy MIC™ Strips (HiMedia).

The STW reaching all 137 surface tanks of all 12 clusters are being monitored by the authors. The fourth tank in Cluster 2 i.e., Chowdenahalli Tank which was one of the earliest tanks to receive STW and is likely to be stabilized over this period was chosen as a representative tank for comparative analysis. However, one representative tank from each of the 12 clusters is reported in Table B.1 of appendix B.

2.2.2. Groundwater (GW) level and quality

To find the impact of STW recycling on GW recharge and water quality, Narasapura borewell which was within 2 km of Chowdenhalli tank was identified for this study. Historical data on GW levels and water quality were obtained from the Karnataka Ground Water Authority (KGWA) and precipitation data were obtained from the Karnataka State Natural Disaster Monitoring Centre (KSNDMC). The parameters studied for GW quality analysis were pH, EC, total dissolved solids (TDS), nitrate (NO_3^-), sulfate (SO_4^{2-}), phosphate (PO_4-P), sodium (Na^+), Calcium (Ca^+), chloride (Cl^-), magnesium (Mg^+), potassium (K^+), and fluoride (F^+). Though one representative borewell data is provided in the main text, GW quality data of 12 representative borewells, around tanks (Table B.1), for all 12 clusters is provided in Table B.2 of appendix B.

2.2.3. Socio-economic status

Villages that are nearest (within 2–3 km) to the tanks filled with STW have been considered "impacted" or experiencing benefits from STW recycling and villages where the tank has not received STW continue to remain status quo of being drought-prone/rain-fed, are considered "non-impacted".

To assess the socio-economic impact of the K&C valley project, a two-step data collection process was followed i.e., 1) approaching farmers through a structured household survey and 2) reaching out to different government organizations of Kolar district such as the department of agricultural & horticulture, department of veterinary sciences, Kolar-district co-operative milk producer's societies union ltd., department of fishery sciences and district surveillance office. Consecutive data for a 6-year period, between 2016 and 2021, were collected for Kolar district from these organizations. Data between 2016 and 2018 were categorized as 'pre-recycling' and that between 2019 and 2021 as 'post-recycling' data.

The present study covered 12 villages in the Kolar district comprising 6 villages from impacted areas and 6 from non-impacted areas to carry out a comparative study to analyse the impact of the K&C valley project and its sustainability. It was ensured that the selected impacted and non-impacted villages were within the Kolar district with the same geographical, hydrological, socio-cultural, agro-climatic, and environmental conditions. The largest distance between impacted and non-impacted areas was just 55 km. Also, the impacted and non-impacted groups of farmers represent typically the predominant 'small and marginal farmers' (SMF, 1-2 ha land holding) and have been carrying out a similar pattern of agricultural

[redacted]

Fig. 1. A schematic framework indicating common and differentiating factors.

activities for a reasonably long period. The predominant difference between the impacted and non-impacted areas was the availability of STW in the tanks and shallow GW levels because of this recycling. A schematic framework indicating the common and the differentiating factors between impacted and non-impacted areas is provided in Fig. 1.

Data for the year 2021 was collected from impacted and non-impacted study areas. The number of farmers selected was based on the probability proportional to the size of SMF of the 12 villages. The sample size (n) of farmer's household units in the study area was determined by applying the following formula (Arkin and Colton, 1950; Kadam and Bhalerao, 2010; https://www.surveymonkey.com/mp/sample-size-calculator/) at 95 % of confidence level, where: z = z-score (1.96), d = margin of error (0.05), p = estimated population proportion (0.5, this maximizes the sample size) and N = total number of farmer's household (1035).

$$\frac{Nz^2p(1-p)}{Nd^2 + z^2p(1-p)}$$

According to this formula, 280 sample sizes were found to be ideal for the random sampling method, hence a total of 280 farmers were selected for the present study. The sample distribution of impacted and non-impacted areas is presented in Table 2 and a schematic diagram of the methodology has been represented in Fig. 2.

Table 2
Selection of sample farmer.

Impacted area			Non-impacted area		
Name of village	Number of farmer's household	Sample farmers	Name of village	Number of farmer's household	Sample farmers
Narsapur	130	35	Baiyappanahalli	105	30
Chowdenahalli	100	30	Imarakunte	70	25
Doddvallabbi	80	15	Marasanapalli	85	25
Dinnehosahalli	85	20	Rayalapad	70	20
Kavaraganahalli	90	25	Chillarapalli	60	15
Doddaleri	70	15	Beemaganapalli	90	25

2.2.4. Questionnaire

Field/household surveys have emerged as a standard tool for empirical research in social sciences (Vehovar and Lozar-Manfreda, 2008). In order to achieve the objective of the present study a questionnaire was designed that included 64 questions distributed over 4 segments as represented below. The data set chose a nearly homogenous type of farmers in this region and the critical differences between the two groups were only the access and availability of GW for agriculture and related livelihoods.

i) general information and socioeconomic status including name, age, education, occupation, and income of the respondents.
ii) agricultural activities including information about land ownership, agricultural land, crop pattern/diversification, crop production, source and method of irrigation, no. of livestock, milk production, labour utilization, and sources of income.
iii) lifestyle and property enhancement including the recent purchase of household amenities, agricultural assets, land, refurbishment of house, land value (pre- and post-recycling), and others.
iv) public, animal health, and perception-related questions include whether the incidence of diseases mainly waterborne (cholera, diarrhea, typhoid, etc.) has increased during post-recycled water use, the status of animal health/disease/mortality changes during post-recycling, a general opinion about the negative and positive impact of the project and suggestions.

The questionnaire was structured to be precise on "open and closed-ended questions", and multiple-choice questions to obtain specific data points. The household survey was conducted by administrating a questionnaire from March 2022–May 2022. Verbal informed consent was obtained from respondents before administering the questionnaire and the purpose of the study was conveyed (Lawton et al., 2017; Roy et al., 2018). Head of the families in the study areas were the primary respondents.

2.2.5. Data analysis

An independent student's t-test was performed to verify the statistical significance difference in obtained data between impacted and non-impacted areas. The results are represented as follows: (a) NS (not significant) for $p > 0.05$, (b) $^*p < 0.05$, (c) and $^{**}p < 0.01$. The percentage of change was carried out to analyse the differences between pre-and post-

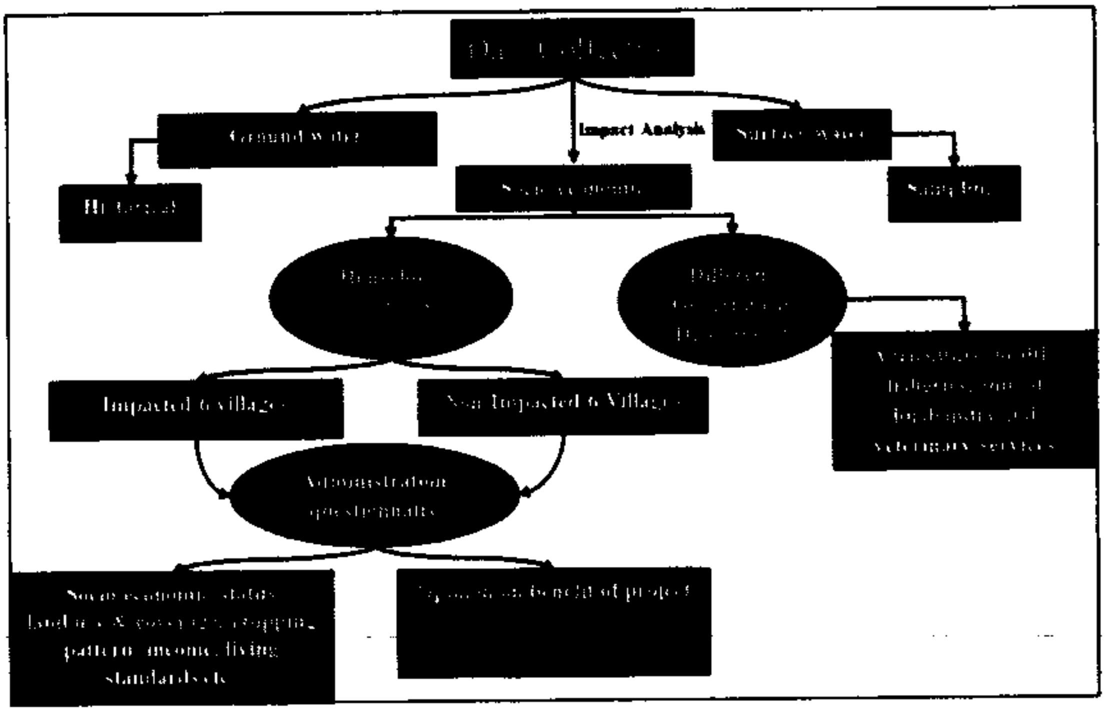

Fig. 2. Schematic diagram of the methodology.

recycling data of Kolar district by taking an average of 3 years for every group.

3. Results and discussion

3.1. Physio-chemical and microbiological analysis of secondary treated water and surface water

The result of the physio-chemical and microbiological analysis of STW at the outlet of STP and surface water of Chowdenahalli tank is presented in Table 3. It indicates that STW from STPs and Chowdenahalli tank were meeting the Hon'ble NGT standard (except for faecal coliform in STW) to dispose of the water into water bodies and for land disposal/applications (NGT, 2019). The results were also meeting three important criteria of the CPCB "Designated best uses of water" i.e., bathing water quality (B), propagation of wildlife and fisheries (D), and irrigation (E).

Table 3
Water quality of secondary treated water and surface tank.

Parameters	[1]Hon'ble NGT standard	[2]CPCB (Designated-best-use water quality)	STW from the outlet of STP	Chowdenahalli tank
pH	6.5–9.0	6.5–8.5 $^{A-E}$	7.6	7.4
BOD_5 (@20 °C) (mg/l)	10	$\leq 2^A$, $\leq 3^B$	9 ± 1.0	3.7 ± 0.8
COD (mg/l)	50	NS	48 ± 4.0	45 ± 4.0
TSS (mg/l)	10	NS	8 ± 2.2	6.5 ± 1.5
TN (mg/l)	10	NS	7.8 ± 2.5	1.5 ± 0.1
NH_4-N (mg/l)	5	1.2^D	4.6 ± 0.8	0.1 ± 0.02
Faecal Coliforms (MPN/100 ml)	<230	$\leq 50^A$, $\leq 500^B$ $\leq 5000^C$	280 ± 20	190 ± 26
PO_4-P (mg/l)	1	NS	0.8 ± 0.3	0.3 ± 0.08
DO (mg/l)	NS	$\geq 6^A$, $\geq 5^B$, $\geq 4^{C,D}$	4.5	8.5 ± 2.1
EC (@25 °C, μs/cm)	NS	2250	707	587 ± 21.5
SAR (mEq/l)	NS	26^E	9.3	3.1 ± 1.0
B (mg/l)	NS	2^E	1.2 ± 0.4	0.5 ± 0.18

Source: [1]NGT, 2019; CPCB, 2013 cpcb.nic.in.
Note: A: Drinking Water Source without conventional treatment but after disinfection; B-Outdoor Bathing; C: Drinking water source after conventional treatment and disinfection; D-Propagation of Wildlife and Fisheries; E-Irrigation, Industrial Cooling, Controlled Waste disposal.
NS: not specified; SAR-sodium absorption ratio; DO- dissolved oxygen.

3.2. Analysis of heavy metals, personal care, and pharmaceutical products (PCPPs)

Given the risks of heavy metals on human health, heavy metal is being monitored regularly, not only in the STW generated in STPs but also in raw sewage entering STPs. Table 4 gives a typical analysis of the heavy metals in the raw sewage entering the STPs and STW being supplied from the STPs to the tanks. As can be seen from Table 4, both the raw sewage and STW meet the existing drinking water standards IS 10500 for heavy metals (Rao et al., 2021). The STW has been constantly monitored for heavy metal content and has been reported to be within acceptable limits (Singh, 2020).

It is important to note that, based on the analysis of heavy metals in raw sewage and STW at the STPs, it is clear that there are no serious threats to human health as far as heavy metals are concerned. Further, the sewage generated undergoes a four-layered purification process namely 1. an anaerobic stage during its conveyance in the sewerage system, 2. a conventional aerobic sewage treatment system that meets the NGT standards (NGT, 2019) (Table 3), 3. a > 14 days residence time in contact with algal system in the open water body and 4. a long passage over hundreds of meters of soil contact before recharging GW. This greatly enhances the potential for nearly complete biodegradation of the slow-to-degrade PCPPs (Narain-Ford et al., 2020). Studies on PCPPs for these locations are underway and preliminary results indicate that common PCPPs such as Ibubrofen, Diclofenac, Azithromycin, Ciprofloxacin, Cetirizine, and Triclosan were absent in the STW.

3.3. Impact on groundwater level and quality

Fig. 3 represents the historical GW level of Narsapura borewell which was in the nearby vicinity (within 2 km) of impacted Chowdenahalli tank. It can be observed from Fig. 3 that the depth of the water level in the Narsapura borewell was approximately 18 mbgl in (Jan-May) 2019

Table 4
Summary of heavy metals analysis.

S.No.	Metals, metalloids, and heavy metals	IS 10500 (mg/l)	Raw sewage (mg/l)	Secondary treated wastewater(mg/l)
1	Iron (Fe)	3	0.40	0.36
2	Manganese (Mn)	2	0.16	0.02
3	Zinc (Zn)	5	0.02	BDL
4	Cadmium (Cd)	2	BDL	BDL
5	Lead (Pb)	0.1	BDL	BDL
6	Arsenic (As)	0.2	0.001	0.001
7	Chromium (Cr^{+5})	0.1	0.004	<0.1
8	Nickel (Ni)	3	0.02	0.028
9	Copper (Cu)	3	0.00005	0.00
10	Aluminium (Al)	0.2	0.03	BDL
11	Barium (Ba)	0.7	0.01	0.045
12	Boron (B)	0.5	0.04	0.021
13	Selenium (Se)	0.01	0.008	BDL
14	Silver (Ag)	0.1	0.00041	BDL
15	Mercury (Hg)	0.001	0.004	BDL
16	Molybdenum (Mo)	0.07	0.003	0.001

Note: BDL is below the detection limit of 1×10^{-6} mg/L

whereas it reached 3 mbgl in July 2019. A clear positive impact on GW levels (83 %) was observed in the studied borewell as an immediate impact of recycling STW. It can be confirmed that the surface water has infiltered into the subsurface and percolated vertically through soil permeability. The downward flow of water through gravity reaches the water table and increases the levels in the GW reservoir. Similar studies are also reported by Nandan et al. (2021) who have reported improved GW conditions in water-scarce regions through managed aquifers. Shawaqfah et al. (2021) reported GW table recovery to 39.68 m by using treated wastewater as GW recharge. Fig. 3 also represents the precipitation data which proves that 2018–2019 was a rain deficit year in the Kolar district but still the water level increased at the studied location which significantly confirms that the increase in GW level is a direct impact of STW recycling which is filled in the respective tank at the studied borewell location.

Table 5 represents a comparison between the pre-recycling (2018) and post-recycling (2021) phases in the historical water quality data of the Narsapura borewell. It can be observed from Table 5 that the GW quality has improved post recycling in the case of all the studied significant parameters. It can be observed that post recycling there was no major change in the pH and the nature of the GW was alkaline (pH = 7.5). Significant reduction was observed in NO_3^- (25 %), SO_4^{2-} (42 %), F^+ (52 %), PO_4-P (20 %), and Cl^- by (52 %) when compared with pre recycling phase. The concentration of cations was also reduced where a reduction in Ca^+ concentration was by 22 %, Na^+ by 13 %, Mg^+ by 36 %, and K^+ by 56 %. It can be concluded that the water quality parameters improved due to the movement of water from the surface tank and through infiltration into the soil, where the water percolates downward deep in the soil and further reaches the water table, and also due to the dilution factor. Analyzing the GW quality is important as it determines its suitability for reuse in irrigation. Bekele et al. (2011) have reported reductions in phosphorous by 30 %, 66 % for fluoride, and 51 % for organic carbon due to GW recharge experimental studies in managed aquifer systems. The results of the presented study are also supported by the outcomes of Asano and Cotruvo (2004), Bekele et al. (2013), Packialakshmi et al. (2015), and Shawaqfah et al. (2021).

3.4. Impact on agricultural activities and socio-economic status

This section represents the overall impacts of the K&C valley project in different socio-economic sectors such as:

3.4.1. Impact on land use and land coverage (LULC)

3.4.1.1. Comparison between pre- to post-recycling period. Fig. 4 indicates the topographical view of land use and land coverage in the Kolar district. Analysis of land use and land cover of any area is an important research aspect to understand environmental change and sustainability (Vivekananda et al., 2021). The analysis shows almost 6 times improvement in the water spread area of water bodies from 9.01km^2 in 2017 to 61km^2 in 2022. It was observed that area under trees increased from 124 km^2 to 177 km^2 and cropping land increased from 2477km^2 to 2584 km^2 during the same period. A major change was observed in the area under flooded vegetation indicating a 67 times improvement from 0.07 km^2 in 2017 to 4.8 km^2 in 2022. The data for fallow land and rangeland indicated a decrease of 41 % and 32 % during the same period. Fig. 4 establishes the contribution of filled water bodies and minor tanks in the improvement of areas of agricultural or productive land.

3.4.2. Impact on agricultural land

3.4.2.1. Comparison between impacted and non-impacted areas. Fig. 5(a) represents that the area under cultivation of vegetables for the year 2021 was relatively higher in impacted areas (57 ha) compared to non-impacted areas (29 ha). The computed student's *t*-test value confirms that there was

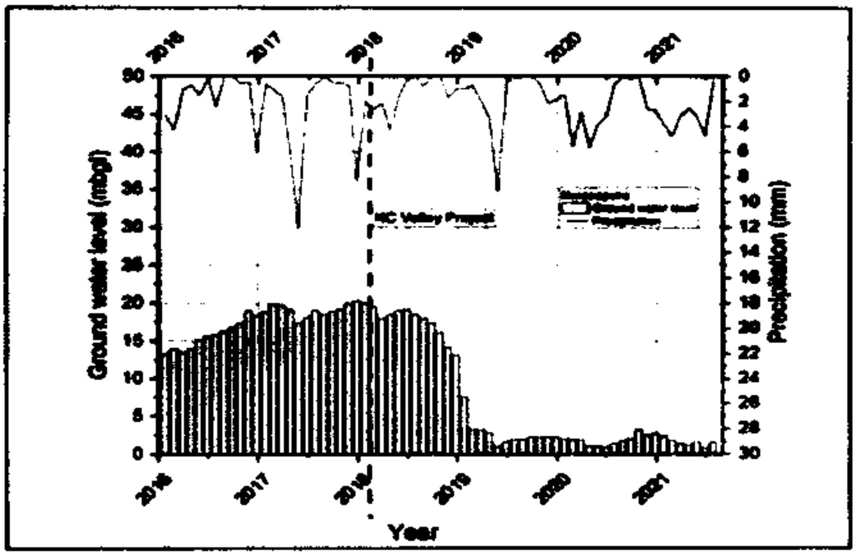

Fig. 3. Change in groundwater level (Narsapura borewell) between pre- to post-recycling period. Source: KGWA & KSNDMC.

Table 5
Change in groundwater quality between the pre- to post-recycling period.

Sl. No	Parameters (unit)	Pre-recycling	Post-recycling
1	pH	7.2	7.5
2	EC (μs/cm)	950 ± 68	404 ± 55
3	TDS (mg/l)	368 ± 22	108 ± 28
4	NO_3^- (mg/l)	2.4 ± 1	1.8 ± 0.4
5	SO_4^{2-} (mg/l)	21 ± 6.2	12 ± 1.8
6	PO_4-P (mg/l)	0.1 ± 0.03	0.08 ± 0.01
7	Na^+ (mg/l)	63.5 ± 12	55 ± 10
8	Cl^- (mg/l)	50.7 ± 8.2	24 ± 5
9	Ca^+ (mg/l)	46.2 ± 8.8	36 ± 8.2
10	Mg^+ (mg/l)	44.7 ± 16	28.2 ± 6.4
11	K^+ (mg/l)	16.2 ± 5.1	7 ± 2.2
12	F^+ (mg/l)	0.84 ± 0.8	0.4 ± 0.1

a significant difference in the mean value of the area under cultivation of vegetables ($p < 0.01$). The student's t-test value confirms that there was a significant difference in the mean value of the area under cultivation of cereals ($p < 0.05$), fruits ($p < 0.01$), and flowers ($p < 0.01$) between impacted and non-impacted areas. It was observed that the area under plantation and pulses was also high in impacted areas compared to non-impacted areas, but a significant difference was not found.

3.4.2.2. Comparison between pre- to post-recycling period. Fig. 5(b) indicates a change in agricultural land of Kolar district from the pre- to post-recycling period. It was observed that the average area under cultivation of vegetables increased from ~20,000 ha to ~33,000 ha from the pre- to post-recycling period which indicates an increase of 65 %. During the same period average area under cultivation of flowers, fruits, and plantation and spices & aromatic (SP & Aroma) crops increased by 68 %, 50 %, 42 %, and 33 % respectively. A minimum increase of 10 %, 9 %, and 7 % was observed for areas under cultivation of pulses, cereals, and oil seeds respectively. It is obvious that due to the assured availability of water the cropping pattern was changed from low water requiring crops (e.g., pulses, oil seed) to high water requiring and water-intensive /water sensitive crops (vegetables, flowers, etc.).

3.4.3. Impact on agricultural (crop) production

3.4.3.1. Comparison between impacted and non-impacted areas. Fig. 6(a) represents that the production of different plantation crops was relatively higher for the year 2021 in impacted areas (23 metric tons (MT)/ha) compared to non-impacted areas (15MT/ha). The computed student's t-test value indicates that there was a significant difference in the mean production of plantation crops ($p < 0.01$). Similarly, the yields of vegetables, flowers, and cereals were high in impacted areas. The student's t-test value confirms that there was a significant difference in the mean yield of vegetables ($p < 0.01$), flowers ($p < 0.01$), and cereals ($p < 0.05$) between impacted and non-impacted areas. It was also observed that the production of pulses was high in non-impacted areas compared to impacted areas, but a significant difference was not found.

3.4.3.2. Comparison between pre- to post-recycling period. Fig. 6(b) indicates improvement in crop production from the pre-to-post recycling period where the average production of flowers, vegetables, plantation, fruits, spices, and aromatic plants and pulses increased by 80 %, 70 %, 36 %, 35 %, 28 %, and 12 %, respectively. While during the same period production of cereals and oil seeds increased by 11 % and 7 % only. It is visible that agricultural production has increased significantly as a result of the assured availability of irrigation water throughout the year, the revival of the GW table, and possibly due to improved GW quality (Theregowda et al., 2019; Tymchuk et al., 2020; Ofori et al., 2021; Partyka and Ronald, 2022). Secured water availability throughout the year resulted in an extended cropping season and a change in cropping pattern. Considering the multidimensional benefits of water security, farmers appear to be more inclined towards cash crops (vegetables, flowers) for quick returns and higher benefits.

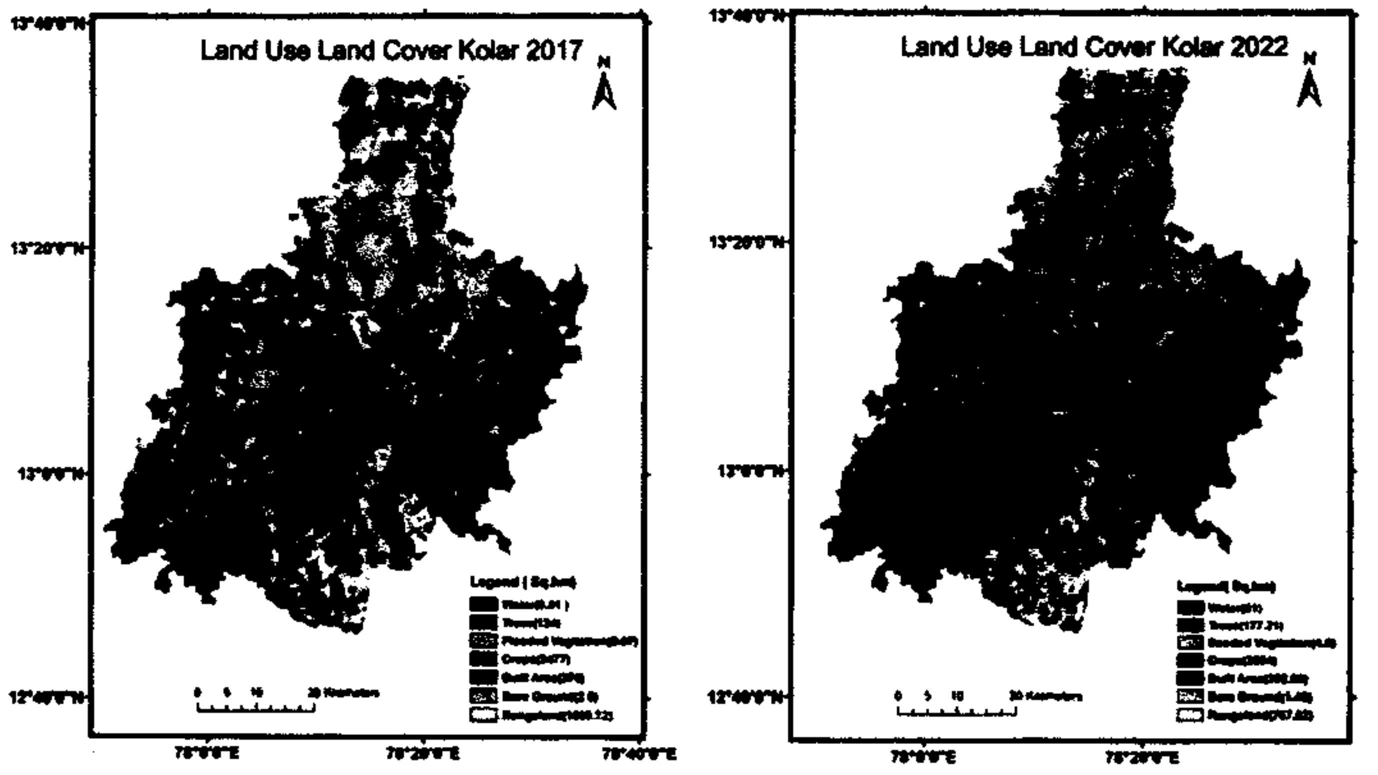

Fig. 4. Change in land use and land cover between 2017 and 2022 in the Kolar district. Source: Environmental Systems Research Institute (ESRI) land cover 2017 to 2022.

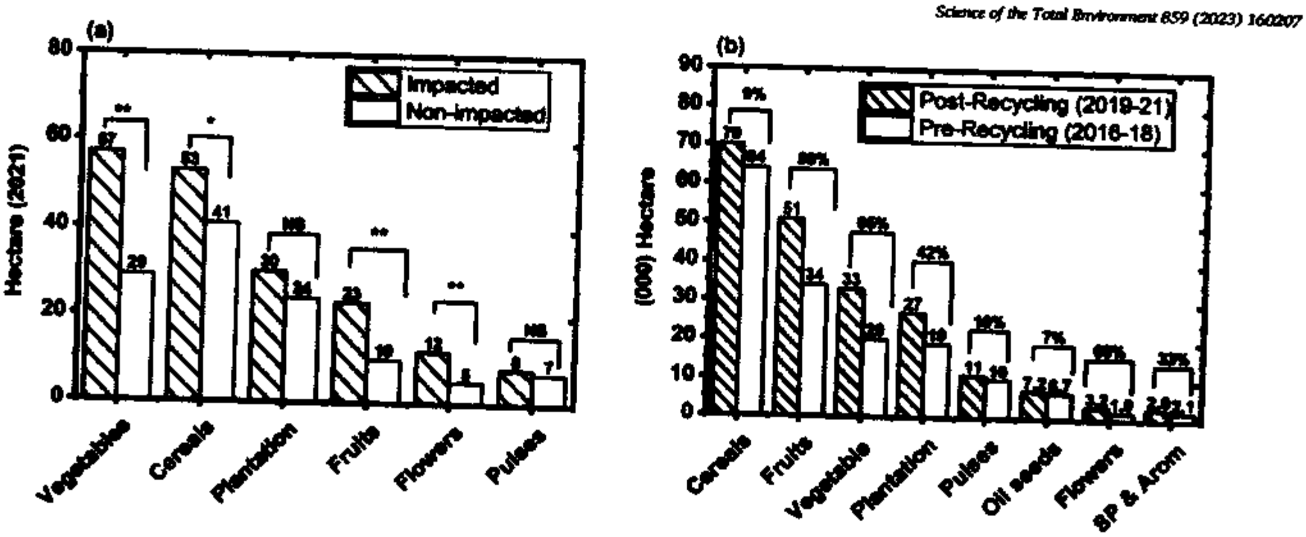

Fig. 5. Change in agricultural land (a) Comparison between impacted and non-impacted areas (b) Comparison between pre- to post-recycling period.
Source: (a) Household survey (b) Department of Agriculture & Horticulture, Kolar
Note: Student's *t*-test value: - vegetables (5.02), Cereals (2.61), Plantation (1.39), Fruits (3.93), Flowers (2.83), Pulses (0.39). NS- not significant for $p > 0.05$, $^*p < 0.05$, $^{**}p < 0.01$. Plantation- cashew, silver oak, eucalyptus, coconut, areca nut, tamarind, and mulberry; Vegetables- tomato, potato, beans, cabbage, green chili, capsicum, carrot, etc.; Fruits- mango, banana, sapota, guava, grapes, watermelon, pomegranates, papaya, etc.; Cereals- ragi, paddy, maize, jowar, minor millets, etc.; Flower- marigold, chrysanthemum, jasmine, rose, crossandra etc.; Pulses-red gram, field bean, toor, cowpea, horse gram, green gram, etc. Oil seed – ground nut, sunflower.

3.4.4. Impact on livestock rearing pattern and milk production

3.4.4.1. Comparison between impacted and non-impacted areas (livestock). Fig. 7 (a) indicates that the number of sheep, goats, cows, and buffalo was higher in impacted areas compared to non-impacted areas in 2021. The computed student's *t*-test value confirms that the difference was significant for sheep ($p < 0.5$), goat ($p < 0.5$), cow ($p < 0.01$), and buffalo ($p < 0.01$).

3.4.4.2. Comparison between impacted and non-impacted areas (milk production). The extent of milk production in impacted and non-impacted areas is presented in Fig. 7(b). The total milk production per day was significantly ($p < 0.01$) higher in impacted areas compared to non-impacted areas at 2141 and 1394 litre.

3.4.4.3. Comparison between pre- to post-recycling period (livestock). Fig. 7(c) shows that the average number of livestock was relatively increased during the post-recycling compared to the pre-recycling period, however, there was no change observed in the pattern of livestock rearing. The average number of cattle increased from 0.16 million to 0.22 million and buffalos also increased from 0.03 million to 0.04 million from the pre- to post-recycling period which indicates a growth of ~37 % and ~33 % respectively. Other livestock such as pigs, sheep, goats, and poultry also witnessed an increase from the pre-to-post recycling period with a reported growth of 100 %, 37 %, 33 %, and 27 % respectively.

3.4.4.4. Comparison between pre- to post-recycling period (milk production). Fig. 7(d) demonstrates taluk level pre- and post-recycling data for the average milk production. It indicates that the average milk production

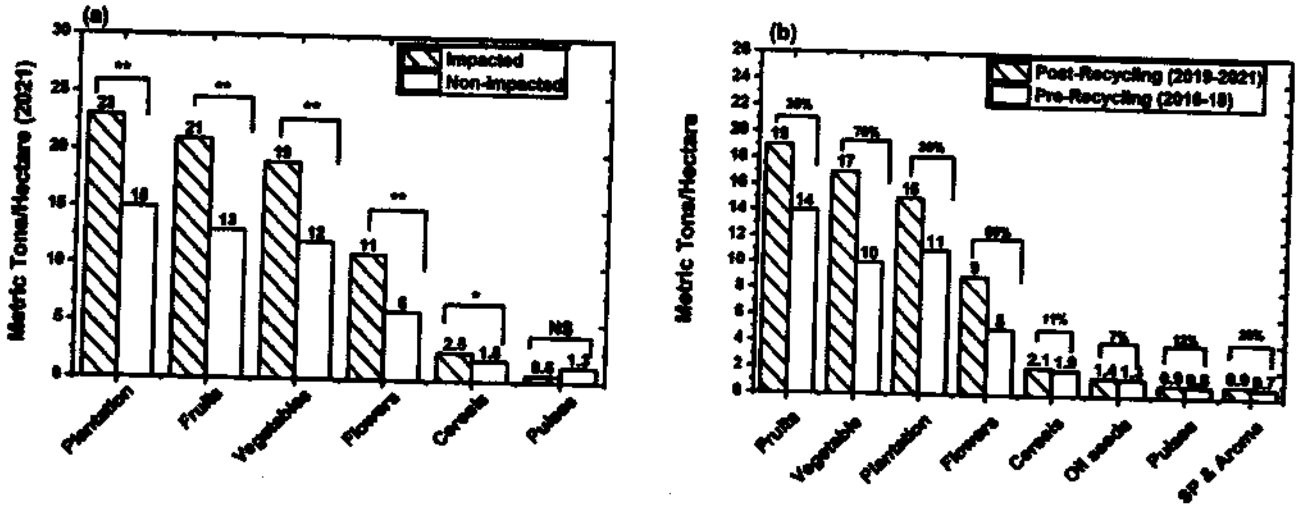

Fig. 6. Change in agricultural production; (a) Comparison between impacted and non-impacted areas (b) Comparison between pre- to post-recycling period.
Source: (a) Household survey (b) Department of Agriculture & Horticulture, Kolar
Note: Student's *t*-test value: - Plantation (4.08), Vegetables (4.67), Flowers (3.79), Cereals (2.91), Fruits (12.08), Pulses (1.89). NS- not significant for $p > 0.05$, $^*p < 0.05$, $^{**}p < 0.01$. Plantation- cashew, silver oak, eucalyptus, coconut, areca nut, tamarind, and mulberry; Vegetables- tomato, potato, beans, cabbage, green chili, capsicum, carrot, etc.; Fruits- mango, banana, sapota, guava, grapes, watermelon, pomegranates, papaya, etc.; Cereals- ragi, paddy, maize, jowar, minor millets, etc.; Flower- marigold, chrysanthemum, jasmine, rose, crossandra, etc.; Pulses-red gram, field bean, toor, cowpea, horse gram, green gram, etc. Oil seed – ground nut, sunflower.

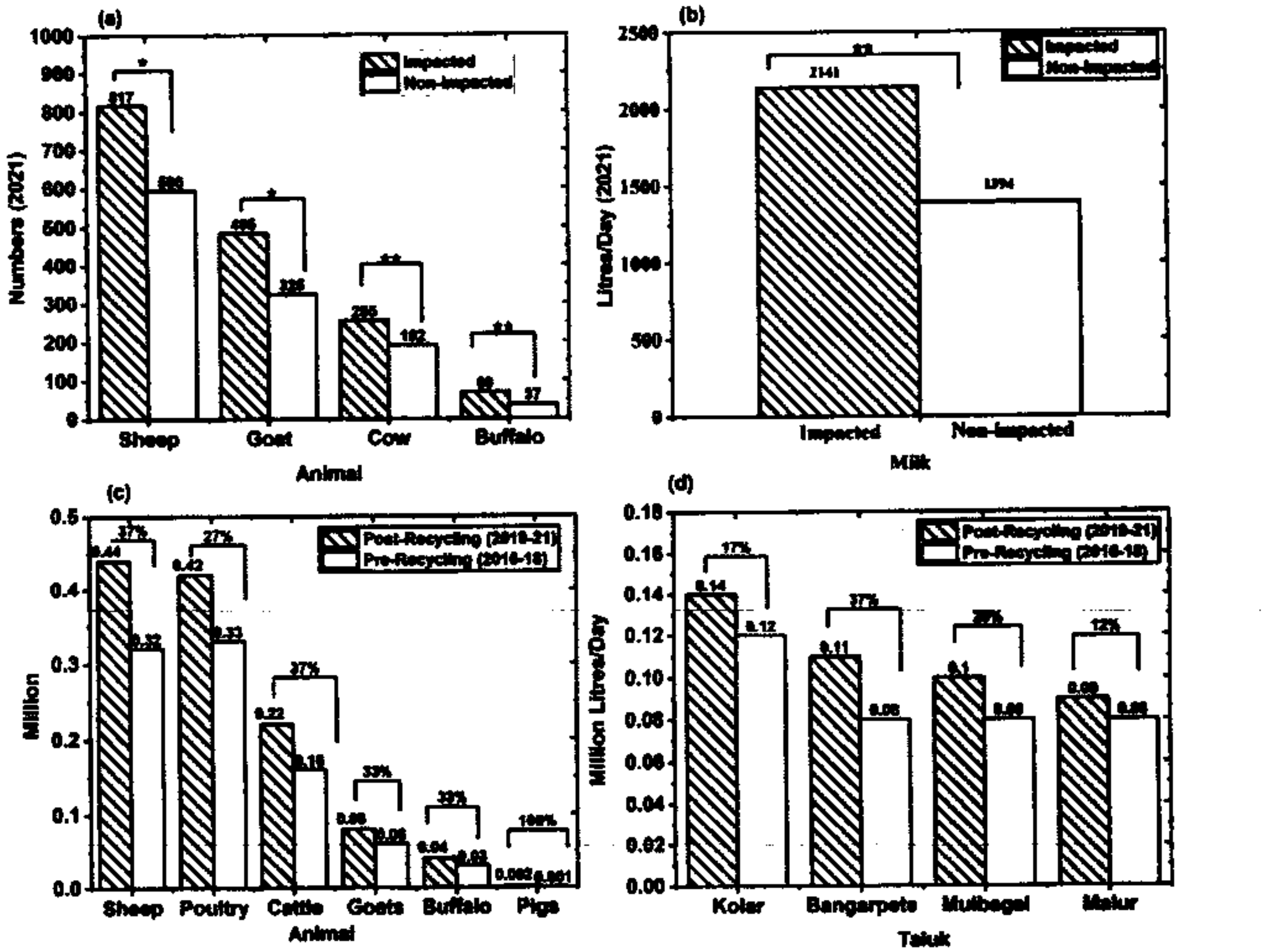

Fig. 7. Change in livestock pattern and milk production; (a) Comparision between impacted and non-impacted areas in pattern of livestock (b) milk production (c) Comparision between pre to post recycling period in the pattern of livestock (d) milk production.
Source: (a & b) Household survey; (c) Department of Veterinary Sciences, Kolar; (d) Kolar-Chikkaballapur District Co-operative Milk Producer's Societies union Ltd. Kolar.
Note: Student's t-test value: - (a) Sheep (20.05), Goat (2.19), Cow (3.77), Buffalo (3.18); (b) milk (7.14). significant for p* < 0.05, **p < 0.01.

increased during the post- recycling period compared to the pre-recycling period. Milk production was increased by 37 % from 0.08 MLD to 0.11 MLD at Bangarpete. Similarly, an increase of 25 %, 17 %, and 12 % in average milk production was reported at Mulbagal, Kolar, and Mular taluks, respectively. Farmers also revealed that the quality and quantity of milk have been improved due to the increased use of green fodder in the daily ration of animals. It is evident from the results that the availability of water has a positive impact on livestock rearing along with milk production.

3.4.5. Impact on fish production

3.4.5.1. Comparison between pre- to post-recycling period. Fig. 8(a) indicates a steep rise in fish farming during the post-recycling period in all taluks of the Kolar district. The highest increase of 300 % was observed at KGF followed by Bangarpete (221 %), Kolar (133 %), Mulbagal (49 %), and Malur (29 %) from the pre- to post-recycling period. Fish farming is one of the most important allied sectors in the Kolar district and occupies an important place in socio-economic development. There were 8091 fish farmers in the Kolar district who were involved in fisheries on a full-time basis and 94,946 fish farmers had taken up fisheries activity as a subsidiary occupation (Department of Fishery Sciences, Kolar, 2021).

3.4.5.2. Comparison between impacted and non-impacted areas. It could be observed from Fig. 8(b) that the average fish production increased by 133 % from 647MT to 1510MT from the pre- to post-recycling period in impacted areas whereas only an 8 % increase was reported from non-impacted areas. The improvement in fish production echoes various supporting statements which elaborated that treated wastewater is favourable for aquaculture due to the presence of a higher concentration of organic matter and other nutrients such as ammonia, nitrite, and potassium which is important for fish growth (Zaibel et al., 2019 & Zaibel and Zilberg, 2021).

3.4.6. Impact on land values

3.4.6.1. Comparison between impacted and non-impacted areas. Fig. 9 represents that the mean price of agricultural land was substantially higher (Rs.2.4 million/ha) in the impacted areas compared to the non-impacted areas (Rs.1 million/ha). From the pre- to post-recycling period land value in impacted areas observed a sharp escalation where prices increased by 118 % compared to a mere 25 % increase in non-impacted areas. Assured availability of water throughout the year resulted in fertile and productive land and has caused this change (Rondhi et al., 2018).

3.4.7. Impact on labour utilization

3.4.7.1. Comparison between impacted and non-impacted areas. It could be observed from Fig. 10(a) that the total number of men labour utilization for the year 2021 in crop activities, livestock, and the non-farm sector was higher in impacted areas at 4248, 2568, and 1149 compared to non-

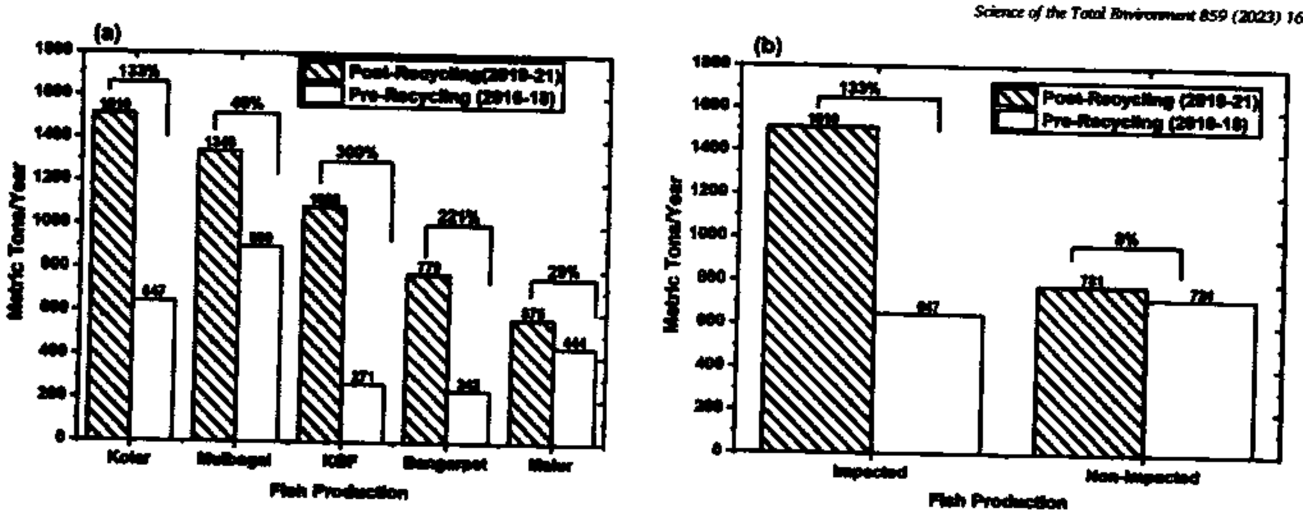

Fig. 8. Change in fish farming (a) Comparison between pre- to post-recycling period (b) Comparison between impacted and non-impacted areas.
Source: (a) & (b) Department of Fishery Sciences, Kolar.
Note: Impacted-Kolar taluk and Non-impacted: Srinivaspur taluk.

impacted areas with 3279, 2019 and 930 respectively. The computed student's *t*-test value indicates that there was a significant difference in the mean score of men's labour utilization in the crop activities ($p < 0.01$), and livestock sector ($p < 0.05$) between impacted and non-impacted areas. However, there were no significant differences observed in the mean score of men's labour utilization in non-farm activities.

Fig. 10(b) indicates that the total number of women labour utilization for the year 2021 in crop activities was higher in impacted areas (6563) compared to non-impacted (4155) areas. Similarly, during the same period, there were substantially higher women's labour utilization observed in impacted areas in livestock and the non-farming sector at 4463 and 2501 compared to non-impacted areas with 2895 and 1122 respectively. The computed student's *t*-test value indicates that there was a significant difference in the mean score of women's labour utilization in the crop activities ($p < 0.01$), livestock sector ($p < 0.01$), and non-farm activities ($p < 0.01$) between impacted and non-impacted areas.

An increase in women's employment pattern reveals that the revival of agricultural activities expanded women's employment opportunities thereby providing unique potential for women's empowerment and influencing involvement in decision making. This observation also supports various studies indicating that empowerment and financial contribution are the most important factor determining the involvement of women in decision-making (Lohani and Aburaida, 2017; Pandey et al., 2021; Kochar et al., 2022).

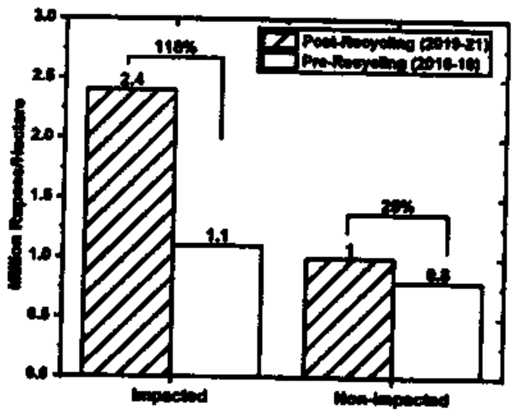

Fig. 9. Change in the value of agricultural land between pre- to post-recycling period
Source: Household survey.

3.4.8. Impact on overall income

3.4.8.1. Comparison between impacted and non-impacted areas. Table 6 indicates that the average net income of farmers was relatively higher in impacted areas compared to non-impacted areas. For instance, the average income from flower cultivation was Rs. 2,27,893/ha in impacted areas whereas Rs. 75,345/ha in non-impacted areas, indicating an increase of 202 %. Similarly, average income from vegetable, plantation and cereals cultivation was also relatively high at Rs. 6,54,672/ha, Rs. 3,72,583/ha and Rs. 49,372/ha in impacted areas compared to Rs. 2,62,143/ha, Rs. 1,93,790/ha and Rs. 32,352/ha at the non-impacted areas, indicating increase of 150 %, 92 % and 53 % respectively. Recourse to multiple cropping as well as increased agricultural crop yields is together responsible for this increase.

It was observed that the average income from livestock was substantially high at Rs. 1,29,200/farm in impacted areas compared to Rs. 93,245/farm in non-impacted areas, indicating an increase of 38 %. Similarly, it was observed that average income from non-farm activities was also relatively higher in impacted areas. Data from multiple sectors reveals that water availability and the increased GW table are playing an important role in the radical improvement of the agro-economic system.

3.4.9. Impact on asset creation - recent purchases of essential and non-essential goods

Table 7 indicates an improvement in the buying pattern of various household goods and agricultural tools in impacted areas. There was a 3-fold increase in the purchase of new four-wheelers. Also, 42 sample farmers from the impacted areas refurbished their houses from "Kutcha" to "Pukka" status as compared to only 19 sample farmers from non-impacted areas. It indicates that an increase in income influenced the purchase behaviour in the sample areas. The positive relationship between socio-economic status and living standards along with the purchase of household goods is already well established (Slama and Tashchian, 1985; Karthika et al., 2015; Mashao and Sukdeo, 2018).

3.4.10. Impact on public health

Table 8 indicates that during the post-recycling period average incidence of water-borne diseases such as typhoid and cholera was reported lower at 3353 and 7 compared to the pre-recycling period with 3409 and 11, this indicates a decrease of 1.6 % and 36 % respectively, whereas the incidence of average diarrhea cases was reported slightly high during post-recycling (46) compared to the pre-recycling period (42). A major surge was reported in chikungunya (182 %) followed by dengue (83 %)

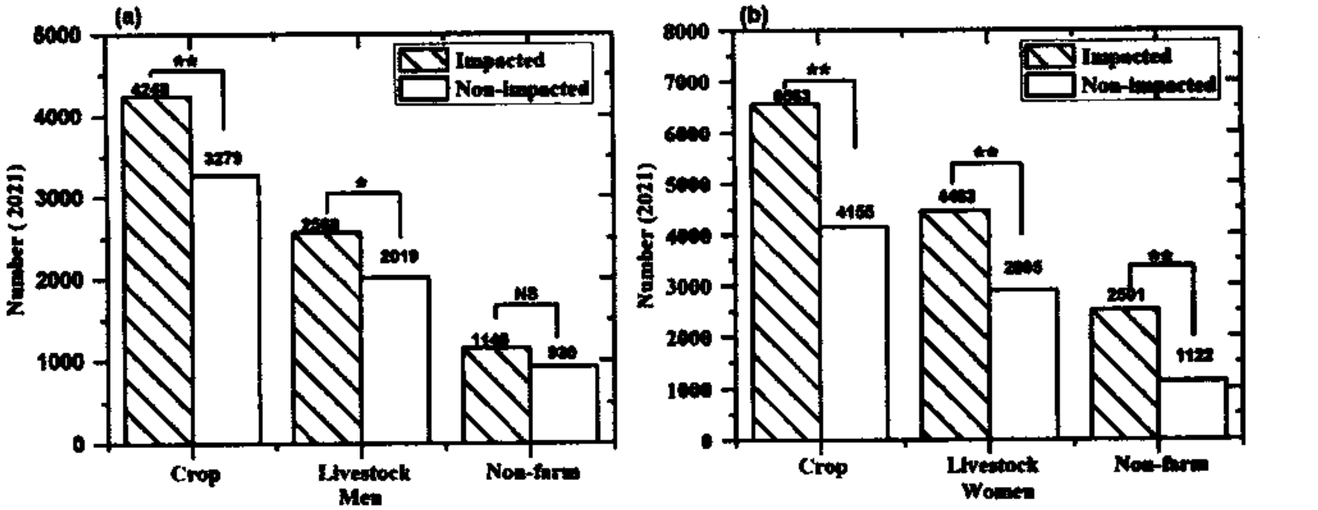

Fig. 10. Change in labour utilization pattern between impacted and non-impacted areas, (a) Men (b) Women.
Source: Household survey
Note: Student's *t*-test value (a) Crop (4.20), Livestock (2.38), Non-farm (1.19). (b) Crop (6.22), Livestock (40.05), Non-farm (4.39). Significant for $^{*}p < 0.05$, $^{**}p < 0.01$.

cases from the pre- to post-recycling period. The incidence of average leptospirosis cases was reported lower during the post-recycling period (5) compared to the pre-recycling period (7).

Over the past 2 years, a noticeable increase in the number of chikungunya and dengue cases was reported across the Karnataka state (www.statista.com) after a long period since India reported re-emerging of the chikungunya outbreak in 2005 (Jain et al., 2020; Sengupta et al., 2020; Sujatha, 2021). Experts from the health department revealed that the increasing numbers of mosquito-borne diseases are a direct consequence of the excess rainfall in the state over the last 2 years, resulting in an expanded pool of stagnant freshwater. This has led to the excess breeding of mosquitoes (Press Trust of India (PTI[a]), 2021) and therefore does not appear to be due to increased GW availability.

Data obtained from the household survey also confirmed that there was no noticeable increase in water-borne diseases in impacted areas compared to non-impacted areas. The occurrence of skin rashes and itching was reported by most of the farmers (80 %) in both the study areas. However, this is certain as a range of studies has established the relation between agricultural workers and skin diseases due to direct exposure to soil, plants, insects, pesticides, sunlight, heat, and infectious agents during farming (Susitaival, 2000; Donham and Thelin, 2016; Bashir et al., 2021).

As discussed in Section 3.2 as far as heavy metals are concerned their presence is below the permissible drinking water standards IS 10500 of India and as such does not pose any serious health risks. Analysis of the health reports for the district and household survey data indicate no increased incidents or chronic impacts due to the presence of chemical compounds in the STW (Sanchez and Egea, 2018; Yadav et al., 2021). However, in order to prevent an undiscovered public health hazard, direct use / contact with water present in tank is prohibited at this stage.

The surface water from the tanks filled with STW and rain-fed tanks in the same region i.e., tanks that did not receive STW but received only rainwater, as controls, were tested. Water in these tanks was studied for antibiotic resistance based on minimum inhibitory concentrations (MIC) of a few representative bacterial species. Resistance to antibiotics such as azithromycin, ciprofloxacin, cefotaxime, amoxicillin + clavulanic acid, cefotoxime + clavulanic acid, and meropenem was studied. These preliminary and ongoing studies indicate a predominance of higher resistance to azithromycin among all the tanks studied i.e., both controls and those receiving STW. However, there were no significant differences in antibiotic resistance levels between these two tanks. Further studies are being

Table 6
Change in income from different units of production between impacted and non-impacted areas.

Sl. No.	Income source in 2021	Impacted farmers (Rs/ha)	Non-impacted farmers (Rs/ha)	Percentage change (%)
I	Crops			
	Cereals	₹ 49,372	₹ 32,352	53
	Vegetables	₹ 6,54,672	₹ 2,62,143	150
	Pulses	₹ 98,027	₹ 93,552	5
	Plantation	₹ 3,72,583	₹ 1,93,790	92
	Flowers	₹ 2,27,893	₹ 75,345	202
II	Livestock	₹ 1,29,200	₹ 93,245	39
III	Non-farm income			
	Service	₹ 48,725	₹ 35,213	38
	Rental Income	₹ 62,352	₹ 27,822	124

Source: Household survey.

Table 7
Change in the new purchase of essential and non-essential goods between impacted and non-impacted areas.

New purchase/assets	Impacted areas	Non-impacted areas	Percentage change (%)
Year	2021	2021	
Household goods	Newly purchase	Newly purchase	
Refurbished house (Kutcha to Pakka)	42	19	121
TVs	62	60	3
Smart phones	163	105	55
Refrigerator	38	17	124
Washing machine	23	11	109
Sofa set	47	21	124
Two-wheeler	27	16	69
Four-wheeler	13	4	225
Agricultural tools			
Seed drill	18	11	64
Wooden plough	6	3	100
Tractor	25	12	108
Sprayer	37	19	95
Pump house	14	5	180
Drip or Sprinkler System	224	226	9
Cattel Shed	44	37	19
Harvesting machines	72	49	47
Seed drill	18	11	64

Source: Household survey.

Table 8
Change in the incidence of diseases between pre to the post-recycling period in the Kolar district.

Diseases	Pre-recycling (2016–18) (Average)	Post-recycling (2019–21) (Average)	Percentage change (%)
Dengue	96	176	83
Chikungunya	67	190	182
Typhoid	3409	3353	(−1.6)
Cholera	11	7	(−36)
Leptospirosis	7	5	(−28)
Diarrheal	42	46	10

Source: District surveillance Office, Kolar.

pursued to explain the generally high prevalence of antibiotic resistance among these water bodies (including control tanks). It has been reported that the strong prevalence of various detergents has triggered the expression of many antibiotic-resistance genes in various representative bacteria and needs further understanding (Khuntia et al., 2019; Khuntia and Chanakya, 2020). It is important to note that, these tanks receiving STW do not form drinking water sources for people in the region but are only used for indirect GW recharge.

3.4.11. Impact on animal health

Observations on major causes and number of animal deaths in the Kolar district are presented in Table 9. The most important change from increased water availability is the increased availability of green fodder and fodder in general leading to better animal nutrition. This is indirectly indicated by the increased level of livestock rearing as discussed earlier. The various other indicators of health, namely commonly occurring diseases and causes of animal deaths were documented in this survey. In general, there were only marginal changes in the pattern of causes of livestock mortality. The average number of cow mortalities was higher during the pre-recycling period (149) than in the post-recycling period (122). From the pre-to-post recycling period, the mortality from bloating and babesia decreased by 12 % and 36 % respectively. Among buffaloes, there were slightly lower mortality from most causes. It was also noted that cow mortality was higher than buffalo. The mortality from waterborne diseases was negligible in livestock animals since direct consumption of treated wastewater was restricted.

3.4.12. Opinion of the sample farmers of impacted areas on the overall benefit of the availability of water in tanks

According to Table 10, the overall opinion of the sample farmers on the availability of water in tanks was recorded. According to the results, 93 % of sample respondents claimed that the availability of water in tanks have a significant impact on agriculture production. According to 88 % of the farmers, GW levels increased substantially, 78 % noted an improvement in sanitation and hygiene, and 76 % said their incomes have increased. According to 67 % of respondents, cropping patterns have changed and there is now an option to grow multiple crops along with vegetables and flowers, 62 % reported that water availability and accessibility have increased, 59 % reported borewell rejuvenation, 58 % said that women empowerment has increased, 58 % claimed an increase in livestock rearing and milk production, 49 % confirmed about the rise in lifestyles and purchasing power and 43 % stated that fallow and barren land has been converted into fertile or productive lands. In the survey, 29 % reported that bird movement and migration increased and 21 % also informed that some of these farmers who had migrated to urban areas for employment have returned to the village and are now farming once again. This is a clear demonstration of reverse migration, an important indicator for improvements in the agricultural sector. This study provides empirical evidence that the K&C valley project has created the potential to improve the agro-economic situation, food security, and environmental aspects, thus building a circular economy, and has been documented in this study.

The study provides empirical evidence that treated wastewater in tanks increases agricultural activities and incomes. Results of this study support the findings of Pedrero et al. (2010), Sathaiah and Chandrasekaran (2020), Busaidi and Mushtaque (2017) which indicate a positive relation between using treated wastewater in agriculture and improvement in agricultural production. A study by Nandan et al. (2021) reveals that the availability of water in tanks increases the GW table, agricultural production, and socio-economic development while reducing the power consumption in water-scarce regions of Telangana state.

4. Conclusion and policy recommendation

The present study quantifies the socioeconomic impacts of the large-scale secondary treated wastewater (STW) from an urban city to neighbouring areas. About 440 MLD of STW from Bengaluru was pumped to Kolar to fill 137 existing surface water tanks to achieve indirect GW recharge. The results show that the STW in the surface water tanks complies with the most stringent standards set by India's The Hon'ble NGT and three important criteria of CPCB's "designated best uses of water" i.e., bathing water quality (B), wild-life propagation and fisheries management (D), and irrigation (E). As a consequence of this project, the surface tanks receiving water have now become a hotspot for biodiversity, with rapid improvement in fish production and bird movement. Outcomes of this study have revealed a greater range of benefits in impacted areas, such as replenishment of GW table, rejuvenation of borewells and open-wells, and improved water security. Significant improvements were observed in crop productivity (flower-80 %, vegetables-70 %, plantation-36 %, and fruits-35 %), an extension of the cropping season, an increase in livestock rearing (cattle-37 % and buffalo-33 %), milk production (Bangarpete- 37 %, Mulbagal- 25 % and Kolar-17 %), land value (118 %) and income. This project has created new job opportunities and reverse migration from urban to rural areas. Improvements in agricultural activities also led to an increase in on-farm employment opportunities for women, which in turn had an impact on decision-making in all domestic spheres. No direct negative effects were reported on public and animal health as a result of GW recharge. Whereas it is recommended to investigate long term impacts of indirect groundwater recharge further deeply through STW on public health in the studied population as usually, they are bio-accumulating.

Similar to Jakkur and Puttenahalli in Bengaluru (which received treated wastewater) (Inayathulla and Paul, 2013; Ramachandra et al., 2020; Pinglay, 2021), this initiative has also become a model for a

Table 9
Major causes and number of animal death in the Kolar district.

Diseases	Cow (Average)			Buffalos (Average)		
	Pre-recycling (2016–18)	Post-recycling (2019–21)	Percentage change (%)	Pre-recycling (2016–18)	Post-recycling (2019–21)	Percentage change (%)
Bloating	80	71	(−12)	6	5	(−17)
Babiosis	30	19	(−36)	2	1	(−50)
Other diseases*	39	32	(−18)	11	7	(−36)
Total	149	122	(−18)	19	13	(−31)

Source: Department of Veterinary Sciences, Kolar.
Note: Other diseases-Anaplasmosis, Downer cow syndrome, Choke, Food/plant poisonings.

Table 10
Opinion of the sample farmers of impacted areas on the overall benefit of treated wastewater stored in tanks.

Particulars	Yes (%)	Particulars	Yes (%)
Agricultural production increased	93	Employment of women increased	58
Groundwater level increased	88	Change in livestock pattern	58
Sanitation, hygiene and cleanliness of surrounding areas improved	78	Increased in milk production	58
Income increased	76	Lifestyle improved	49
Crop pattern changed (multiple crop/vegetables)	67	Transformation of bare land to productive land	43
Easy accessibility of water	62	Bird movement/migratory bird	29
Borewell started functioning or properly functioning	59	Rural migration	21

Source: Household survey.

waste water management system that allows GW recharge and biodiversity to be enhanced. In addition to enabling a transition from urban to rural water recycling, this project contributes to the transition towards the circular economy in the water sector, which is beneficial at several levels: economics, environment, social and cultural. The availability of water in tanks facilitates local recharge throughout the year and rejuvenation of borewells provides support to small and marginal farmers who cannot afford to deepen borewells or pay the cost of the declining GW table.

To shorten the gaps between water supply and demand, the results of this study will eventually help the different stakeholders including central, state, district, and local government authorities to draft and implement policies to encourage integrated planning, and management of wastewater reuse for GW recharge. This in turn has a sustainable approach to resolving water crises and has a high potential to improve the agro-economic system and food security. The establishment of a proper monitoring system awareness and training program among farmers about the selection of crop patterns, fertilizer use, and irrigation technique must be in place for a sustainable outcome. The involvement of the community in decision-making, planning, and implementation is also vital for the success of the project. To promote the reuse of recycled water, a public-private partnership (PPP) should be established, similar to the Nagpur model (Press Trust of India (PTIb), 2021), in which 90 % of wastewater was reused. Furthermore, it illustrates how PPP can enhance water security and reduce wastewater burden by reusing treated wastewater.

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CRediT authorship contribution statement

Manjari Manisha – Corresponding Author, study design, data collection, analysis, designing and drafting of the manuscript.
Kavita Verma – Study design, analysis and drafting.
Ramesh N – Data collection, designing of the manuscript.
Anirudha TP – Data collection, designing of the manuscript.
Santrupt RM – Data collection, designing of the manuscript.
Reshmi Das – Data collection.
Mohan Kumar MS – Conception, designing of the study and review of the article.
Chanakya HN – Conception, designing of the study and review of the article.
Lakshminarayana Rao – Conception, designing of the study and review of the article.

Data availability

Data will be made available on request.

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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References

Abusam, A., Shahalam, A., 2013. Wastewater reuse in Kuwait: opportunities and constraints. WIT Trans. Ecol. Environ. 179, 745–754.
Aleisa, E., 2019. Analysis on reclamation and reuse of wastewater in Kuwait. J. Eng. Res. 7 (1).
Aly Gondia, M.K., Bakr, M., Mohamed, A.G., 2021. Sustainable management of treated wastewater, the New El-Mahsama wastewater treatment plant in Sinai. J. Environ. Treat. Tech. 9 (4), 804–814.
APHA, 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.
Arkin, H., Colton, R.R., 1950. Tables for Statisticians. Barnes and Noble Publication New.
ARMCAN, ANECC, NHMRC, Agriculture and Resource Management Council of Australia and New Zealand, Australian and New Zealand Environment and Conservation Council, National Health and Medical Research Council, 2000. National Water Quality Management Strategy. Guidelines for Sewerage Systems: Use of Reclaimed Water, Australia Available at: use-reclaimed-water.pdf (waterquality.gov.au).
Asano, T., Cotruvo, J.A., 2004. Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. Water Res. 38 (8), 1941–1951.
Ballukraya, P.N., 1997. Groundwater over exploitation: a case study from Moje-Anepura, Kolar District, Karnataka. J. Geol. Soc. India 50 (3).
Bashir, S., Hassan, I., Wani, R.T., Zeerak, S., Shah, F.Y., 2021. Pattern of skin diseases and occupational dermatoses among paddy field workers in Kashmir Valley: a cross-sectional study from North India. Indian J. Community Med. 46 (4), 610–613.
Bekele, E., Toze, S., Patterson, B., Higginson, S., 2011. Managed aquifer recharge of treated wastewater: water quality changes resulting from infiltration through the vadose zone. Water Res. 45 (17), 5764–5772.
Bekele, E., Toze, S., Patterson, B., Fegg, W., Shackleton, M., Higginson, S., 2013. Evaluating two infiltration gallery designs for managed aquifer recharge using secondary treated wastewater. J. Environ. Manag. 117, 115–120.
Bera, B., Shit, P.K., Sengupta, N., Saha, S., Bhattacharjee, S., 2022. Steady declining trend of groundwater table and severe water crisis in unconfined hard rock aquifers in extended part of Chota Nagpur Plateau, India. Appl. Water Sci. 12 (3), 1–19.
Biswas, A.K., Hartley, K., 2017. From evidence to policy in India's groundwater crisis. The Diplomat.
Busaidi, A.A., Mushtaque, A., 2017. Maximum use of treated wastewater in agriculture. Water Resources in Arid Areas: The Way Forward. Springer International Publishing AG.
Chindarkar, N., Grafton, R.Q., 2019. India's depleting groundwater: when science meets policy. Asia Pac. Policy Stud. 6 (1), 108–124.
CGWB, Central ground water board, 2016. Kolar taluk aquifer maps and management plans, Kolar district, Karnataka. Available at http://cgwb.gov.in/AQM/NAQUIM_REPORT/karnataka/Kolar.pdf.

NEERI, National Environmental Engineering Research Institute, 2015. Available at: Project Completed, Page - 4 - Water Technology and Management Division/The Official Website of CSIR-National Environmental Engineering Research Institute, Government of India.

CPCB Central Polution Control Board, 2013. Available at Designated_Best_Use_Water_Quality_Criteria.pdf (cpcb.nic.in).

Dangar, S., Asoka, A., Mishra, V., 2021. Causes and implications of groundwater depletion in India: a review. J. Hydrol. 596.

Deepa, K., Krishnaveni, M., 2012. Water quality performance of soil aquifer treatment (SAT) using municipal treated wastewater of Chennai city, India. J. Environ. Hydrol. 20 (2).

DEIAA, 2020. District Mineral Survey Report of Kolar District, Karnataka, Mines & Geology Department, Kolar. Available at. http://environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=LkHrLg8Xn4+eAty6Za7I/rwq0QkttR/lZTn7mkRY0XTMLHWQS2uF789q9Y5eKhfKDJUIVvOIdzcaZ2OfurVB3g==&FilePath=93ZZBm8LWEXfg+HAIQIx2fIl2t8z/pgnoBhDIYdZCxxVPEh4a7FS3Cae7tleKGoXIDIA7chYePNgRJpehWx3dLaaLaee8RS5VxBvVdCAnIMg=.

Department of Fishery Sciences, Kolar, 2021. Available at: http://www.fisheries-kolar.com/.

Dillon, P., Arshad, M., 2016. Managed aquifer recharge in integrated water resource management. Integrated Groundwater Management. Springer, Cham, pp. 435–452.

Djamel, G., Noureddine, E., Abdulaziz, A., 2019. Direct potable reuse: the Singapore NEWater Project as a role model. Open Access Libr.J. 6, 1–11.

Donham, K.J., Thelin, A., 2016. Agricultural Skin Diseases. Handbook: Agricultural Medicine: Rural Occupational and Environmental Health, Safety, and Prevention, Second edition John Wiley & Sons, Inc., pp. 155–179.

Engberg-Pedersen, Lars, 2011. Coping With Poverty and Institutionalised Practices: Tank-Irrigated Cultivation in Kolar District, Karnataka. DIS Working Paper.

Essandoh, H.M., Tizaoui, C., Mohamed, M.H., Amy, G., Brdjanovic, D., 2011. Soil aquifer treatment of artificial wastewater under saturated conditions. Water Res. 45 (14), 4211–4226.

Garg, K.K., Anantha, K.H., Nune, R., Akuraju, V.R., Singh, P., Krishna, G.M., Dixit, S., Ragab, R., 2020. Impact of land use changes and management practices on groundwater resources in Kolar district, Southern India. J. Hydrol. Reg. Stud. 31 (100732).

GoK (Government of Karnataka), 2016. District Irrigation Plan – Kolar District. Pradhana Mantri Krishi Sinchayee Yojane (PMKSY) Available at: PMKSY.

Icekson-Tal, N., Avraham, O., Sack, J., Cikure H., I., 2003. Water reuse in Israel - the Dan Region Project: evaluation of water quality and reliability of plant's operation. Water Supply 3 (4), 231–237.

Inayathulla, M., Paul, M.J., 2013. Assessment of surface water chemistry of Jakkur Lake, Bangalore, Karnataka, India. Int. J. Sci. Eng. Res. 4 (5), 302–305.

Jain, J., Kaur, N., Haller, S.L., Kumar, A., Rossi, S.L., Narayanan, V., 2020. Chikungunya outbreaks in India: a prospective study comparing neutralization and sequelae during two outbreaks in 2010 and 2016. Am. J. Trop. Med. Hyg. 102, 857–868.

Jhansi, S.C., Mishra, S.K., 2013. Wastewater treatment and reuse: sustainability options. Consilience J. Sustain. Dev. 10 (1), 1–15.

Jodar-Abellan, A., López-Ortiz, M.I., Melgarejo-Moreno, J., 2019. Wastewater treatment and water reuse in Spain. Current situation and perspectives. Water 11 (8), 1551.

Kadam, P., Bhalerao, S., 2010. Sample size calculation. Int. J. Ayurveda Res. 1 (1), 55–57.

Kanarek, A., Michail, M., 1996. Groundwater recharge with municipal effluent: Dan region reclamation project, Israel. Water Sci. Technol. 34 (11), 227–233.

Karthika, R., Anand, N.V., Chandrakhanthan, J., 2015. A study on consumer behaviour towards household goods in Tiruchirapalli District. Aust. J. Basic Appl. Sci. 9 (23), 22–27.

Kesari, K.K., Soni, R., Jamal, Q.M.S., 2021. Wastewater treatment and reuse: review of its applications and health implications. Water Air Soil Pollut. 232, 208.

Khuntia, H.K., Chanakya, H.N., 2020. Accumulation of antibiotic-resistant genes in anaerobic biofilm reactor fed with household chemical products. SN Appl.Sci. 2 (8), 1–7.

Khuntia, H.K., Chandrashekar, S., Chanakya, H.N., 2019. Treatment of household greywater laden with household chemical products in a multi-chambered anaerobic biofilm reactor. Sustain. Cities Soc. 51, 101783.

Kochar, A., Nagabhushana, C., Sarkar, R., Shah, R., Singh, G., 2022. Financial Access and Women's Role in Household Decisions: Empirical Evidence From India's National Rural Livelihoods Project.

Kog, Y.C., 2020. Water reclamation and reuse in Singapore. J. Environ. Eng. 146 (4), 03120001.

Kolar district profile, 2009. Ground Water Information Booklet Available at: Microsoft Word - KOLAR_BROCHURE.doc (cgwb.gov.in).

Lawton, J., Hallowell, N., Snowdon, C., 2017. Written versus verbal consent: a qualitative study of stakeholder views of consent procedures used at the time of recruitment into a peripartum trial conducted in an emergency setting. BMC Med. Ethics 18, 36. https://doi.org/10.1186/s12910-017-0196-7.

Lohani, M., Aburaida, L., 2017. Women empowerment: a key to sustainable development. Soc.ION 6 (26), 9886095465.

Mashao, E.T., Sukdeo, N., 2018. Factors That Influence Consumer Behaviour in the Purchase of Durable Household Products. Conference Paper, IEOM.

Mazari-Hiriart, M., Ponce-de-Leon, S., Lopez-Vidal, Y., Islas-Macias, P., Amieva-Fernández, R.I., Quiñones-Falconi, F., 2008. Microbiological implications of periurban agriculture and water reuse in Mexico City. PLoS One 3 (5), e2305.

Minhas, P.S., Saha, J.K., Dotaniya, M.L., Sarkar, A., Saha, M., 2022. Wastewater irrigation in India: current status, impacts and response options. Sci. Total Environ. 808.

Nagaraj, N., Chandrashekhar, H., Yatheesh, H.S., 2003. Sustainability and equity implication of groundwater depletion in hard rock areas of Karnataka-an economic analysis. Ind. J. Agric. Econ. 58, 438–447.

Nandan, M.J., Surinaidu, L., Kumar, D., 2021. Sustainable irrigation and economic development through community participated managed aquifer recharge in water scarce regions of Telangana state — a case study. J. Geol. Soc. India 97, 1294–1299.

Narain-Ford, D.M., Bartholomeus, R.P., Dekker, S.C., Wezel, A.P.V., 2020. Natural purification through soils: risks and opportunities of sewage effluent reuse in sub-surface irrigation. Rev. Environ. Contam. Toxicol. 250, 85–117.

NGT, National Green Tribunal, 2019. Available at https://greentribunal.gov.in/sites/default/files/all_documents/4th-report-alongwith-annexures_compressed.pdf.

Ofori, S., Puskacova, A., Ruzickova, I., Wanner, J., 2021. Treated wastewater reuse for irrigation: pros and cons. Sci. Total Environ. 760.

Okello, C., Tomasello, B., Greggio, N., Wambiji, N., Antonellini, M., 2015. Impact of population growth and climate change on the freshwater resources of Lamu Island, Kenya. Water 7 (3), 1264–1290.

Packialakshmi, S., Balaji, S., Kumaresan, T., 2015. Inducing recharge of groundwater by treated wastewater—a pilot study in Southern Chennai Metropolitan Area. Indian J. Sci. Technol. 8 (11).

Pandey, P., Choubey, A.K., Rai, G., 2021. The involvement of women as the domestic decision maker: a study of Patna Metropolitan City, Bihar, India. Soc. Nat. 33, e62053.

Partyka, M.L., Ronald, F.B., 2022. Wastewater reuse for irrigation of produce: a review of research, regulations, and risks. Sci. Total Environ. 828.

Pedrero, F., Kalavrouziotis, I., Alarcón, J.J., Koukoulakis, P., Asano, T., 2010. Use of treated municipal wastewater in irrigated agriculture—review of some practices in Spain and Greece. Agric. Water Manag. 97 (9), 1233–1241.

Pinglay, P., 2021. Available at: The Story of Jakkur Lake Sets an Example for Inclusive Rejuvenation Projects - Vikalp Sangam.

Press Trust of India (PTIa), 2021. Available at: Heavy Rainfall Triggering Rise in Dengue Cases in Karnataka | Deccan Herald.

Press Trust of India (PTIb), 2021. Available at: India's 1st and Largest PPP on Waste Water Reuse Completed in Record Time During Pandemic; Bags FICCI Water Award 2020 | Business Standard News (business-standard.com).

Ramachandra, T.V., Varghese Sincy, K.S., Asulabha, 2020. Efficacy of rejuvenation of lakes in Bengaluru, India. Green Chem. Technol. Lett. 6, 14–26.

Ramaiah, S.N., Reddy, R., Reddy, V.J., 2017. Over-exploitation of groundwater, and its impact on phreatic aquifer system, surface water bodies and rural water supply schemes in Malur Taluk, Kolar District, Karnataka - a case study. Nat. Environ. Pollut. Technol. 16, 599–605.

Rao, H., Rao, L., Chanakya, H.N., 2021. Fate of heavy metals in sewage and polluted water bodies. Curr. Sci. 121 (1), 109.

Rondhi, M., Pratiwi, P.A., Handini, V.T., Sunartomo, A.F., Budiman, S.A., 2018. Agricultural land conversion, land economic value, and sustainable agriculture: a case study in East Java, Indonesia. Land 7, 148.

Roy, D., Palavalli, B., Menon, N., 2018. Survey-based socio-economic data from slums in Bangalore,India. Sci. Data 5, 170200. https://doi.org/10.1038/sdata.2017.200.

Sanchez, W., Egea, E., 2018. Health and environmental risks associated with emerging pollutants and novel green processes. Environ. Sci. Pollut. Res. 25, 6085–6086.

Sathaiah, M., Chandrasekaran, M., 2020. A bio-physical and socio-economic impact analysis of using industrial treated wastewater in agriculture in Tamil Nadu, India. Agric. Water Manag. 241 (4).

Sengupta, S., Mukherjee, S., Haldar, S.K., Bhattacharya, N., Tripathi, A., 2020. Re-emergence of Chikungunya virus infection in Eastern India. Braz. J. Microbiol. 51 (1), 177–182.

Shan, V., Singh, S.K., Haritash, A.K., 2020. Water crisis in the Asian countries: status and future trends. Resilience, Response, and Risk in Water Systems, pp. 173–194.

Shawaqfah, M., Almomani, F., Al-Rousan, T., 2021. Potential use of treated wastewater as groundwater recharge using GIS techniques and modeling tools in Dhuleil-Halabat well-field/Jordan. Water 13 (11), 1581.

Singh, U.V., 2020. The recycling of sewage generated in Kormanagala-Chellaghtta valley of Bengaluru India. Adv. Environ. Waste Manag. Recycl. (ISSN: 2641-1784) 3 (2), 47–62.

Slama, M.E., Tashchian, A., 1985. Selected socioeconomic and demographic characteristics associated with purchasing involvement. J. Market. 49 (1), 72–82.

Suhag, R., 2016. Overview of ground water in India. PRS Legis.Res. 9504 (February), 12.

Sujatha, S., 2021. Current status of Chikungunya in India. Front. Microbiol. 12 (3).

Susitaival, P., 2000. Occupational Skin Diseases in Farmers and Farm Workers Kanerva.

Theregowda, R.B., Alejandra, M.G., Ma, Xin Cissy, Garland, J., 2019. Nutrient recovery from municipal wastewater for sustainable food production systems: an alternative to traditional fertilizers. Environ. Eng. Sci. 36 (7), 833–842.

Tortajada, C., Bindal, I., 2020. Water Reuse in Singapore: The New Frontier in a Framework of a Circular Economy. Water Reuse Within a Circular Economy Contex, 2 Available at: Water_reuse_in_Singapore_The_new_frontier_in_a_framework_of_a_circular_economy-with-cover-page-v2.pdf (d1wqtxts1xzle7.cloudfront.net).

Tymchuk, I., Shkvirko, O., Sakalova, H., 2020. Wastewater a source of nutrients for crops growth and development. J. Ecol. Eng. 21 (5), 88–96.

Vehovar, V., Lozar-Manfreda, K., 2008. Overview: Online Surveys. The Sage Handbook of Online Research Methods.

Vivekananda, G.N., Swathi, R., Sujith, L.N., 2021. Multi-temporal image analysis for LULC classification and change detection. Eur. J. Remote Sens. 54 (sup2), 189–199. https://doi.org/10.1080/22797254.2020.1771215 York, pp. 1-10.

WHO, World Health Organization, 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater. Geneva. Available at: who.int.

World Bank, 2010. Deep Wells and Prudence; Towards Pragmatic Action for Addressing Groundwater Over Exploitation in India D.C.Washigton.

World Bank, 2012. India Groundwater: A Valuable But Diminishing Resource.

World Bank, 2018. Wastewater: From Waste to Resource The Case of Atotonilco de Tula, Mexico Available at: World Bank Document.

Yadav, D., Rangabhashiyam, S., Verma, P., Singh, P., Devi, P., Kumar, P., Kumar, K.S., 2021. Environmental and health impacts of contaminants of emerging concerns: recent treatment challenges and approaches. Chemosphere 272, 129492.

Zaibel, I., Zilberg, D., 2021. Treated municipal wastewater as a water source for sustainable aquaculture: a review. Rev. Aquac. 14 (4).

Zaibel, I., Appelbaum, Y., Arnon, S., Britzi, M., Schwartsburd, F., Snyder, S., Zilberg, D., 2019. The effect of tertiary treated wastewater on fish growth and health: laboratory-scale experiment with Poecilia reticulata (guppy). PloS one 14 (6), e0217927.

Annexure - VIII

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Assessing groundwater recharge rates, water quality changes, and agricultural impacts of large-scale water recycling

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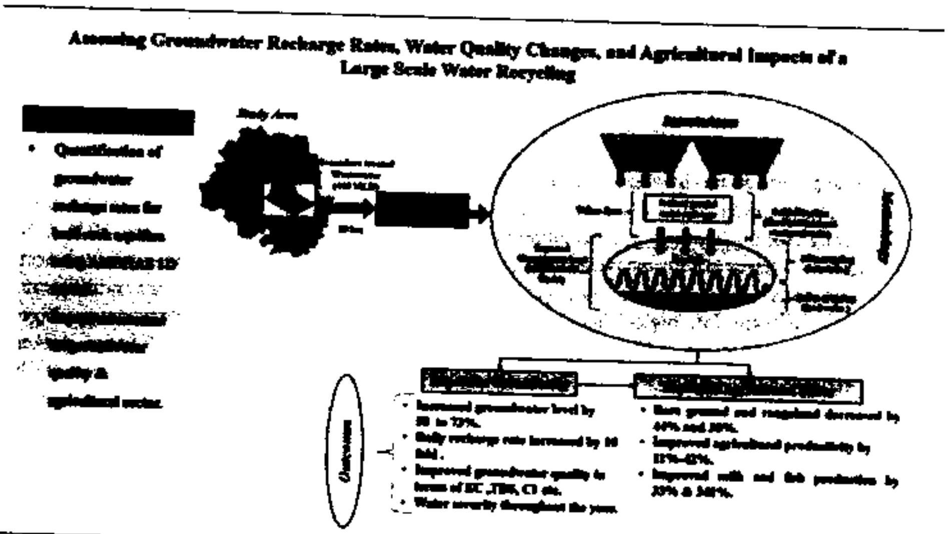
HIGHLIGHTS

- 10× improvement in daily groundwater recharge rates
- Groundwater levels increased by 58 % to 73 %
- Groundwater quality improved due to higher groundwater infiltration
- Significant improvement in agricultural productivity
- Sustainable solution for freshwater security and wastewater management

GRAPHICAL ABSTRACT



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ABSTRACT

The over-exploitation and insufficient replenishment of groundwater (GW) have resulted in a pressing need to conserve freshwater and reuse of treated wastewater. To address this issue, the Government of Karnataka launched a large-scale recycling (440 million liters/day) scheme to indirectly recharge GW using secondary treated municipal wastewater (STW) in drought-prone areas of Kolar district in southern India. This recycling employs soil aquifer treatment (SAT) technology, which involves filling surface run-off tanks with STW that intentionally infiltrate and recharge aquifers. This study quantifies the impact of STW recycling on GW recharge rates, levels, and quality in the crystalline aquifers of peninsular India. The study area is characterized by hard rock aquifers with fractured gneiss, granites, schists, and highly fractured weathered rocks. The agricultural impacts of the improved GW table are also quantified

Abbreviations: APHA, American Public Health Association; ARB, Antibiotic Resistance Bacteria; BCM, Billion Cubic Meters; BIS, Bureau Indian Standard; BWSSB, Bengaluru Water Supply and Sewerage Board; CGWB, Central Ground Water Board; DEIAA, District Level Environment Impact Assessment Authority; ESRI, Environmental Systems Research Institute; GoK, Government of Karnataka; GW, Groundwater; ICPMS, Inductively Coupled Plasma Mass Spectrometry; K&C, Koramangala and Challaghatta; KGWA, Karnataka Groundwater Authority; KSNDMC, Karnataka State Natural Disaster Monitoring Centre; KSPCB, Karnataka State Pollution Control Board; LCMS, Liquid Chromatography- Mass Spectrometry; MAR, Managed Aquifer Recharge; MI & GW, Minor Irrigation and Groundwater; MLD, Million Liters per Day; NGT, National Green Tribunal; SAT, Soil Aquifer Treatment; STP, Sewage Treatment Plant; STW, Secondary Treated Wastewater.

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by comparing areas receiving STW to those not receiving it, and changes before and after STW recycling were measured. The AMBHAS_1D model was used to estimate the recharge rates and showed a tenfold increase in daily recharge rates, resulting in a significant increase in the GW levels. The results indicate that the surface water in the rejuvenated tanks meets the country's stringent water discharge standards for STW. The GW levels of the studied boreholes increased by 58–73 %, and the GW quality improved significantly, turning hard water into soft water. Land use land cover studies confirmed an increase in the number of water bodies, trees, and cultivated land. The availability of GW significantly improved agricultural productivity (11–42 %), milk productivity (33 %), and fish productivity (341 %). The study's outcomes are expected to serve as a role model for the rest of Indian metro cities and demonstrate the potential of reusing STW to achieve a circular economy and a water-resilient system.

1. Introduction

An increasing global population, industrial growth, urbanization, land use changes, and limited precipitation have caused a worldwide scarcity of freshwater, putting pressure on groundwater (GW) resources (Modrzynski et al., 2021; McCance et al., 2020; Wakode et al., 2018; Okello et al., 2015). India is the largest user of GW, with over 50 % of its rural population relying on it for basic needs (Garg et al., 2022). It is estimated that 17 % of India is overexploited due to excessive extraction of GW (58–65 % in 2020), reducing annual recharge from 447 billion cubic meters to 432 BCM (Dangar et al., 2021; GoI, 2021; CGWB, 2020; Hussain et al., 2017). To prevent further depletion, long-term water management strategies are crucial, with artificial GW recharge methods such as the use of rainwater and treated wastewater for improving the GW table. (Chen et al., 2023; Dihan et al., 2023; Manisha et al., 2023; Dillon and Arshad, 2016). Managed aquifer recharge (MAR) is a common technique for preserving GW by intentionally infiltrating water from the surface into GW and addressing freshwater scarcity (Sunyer-Caldú et al., 2023; Alam et al., 2021; Grinshpan et al., 2021; Ganot et al., 2018). MAR is achieved through techniques such as percolation tanks, rainwater harvesting, soil aquifer treatment (SAT), and infiltration basins (Alam et al., 2021).

SAT is a globally practiced wastewater recycling method under MAR that converts wastewater into high-quality recharge effluent by removing contaminants as wastewater infiltrates through soil layers (Grinshpan et al., 2021; Wei et al., 2015; Rahman et al., 2012; Icekson-Tal et al., 2003). Successful GW recharge schemes based on SAT are summarised in Table 1. The reported GW recharge rate, soil type, and changes in GW quality are also tabulated in Table 1. As can be seen from Table 1, GW recharge rates vary significantly even in sandy and sandy loamy soils, from 13.2 mm/day to 110 mm/day, with varying degrees of GW quality improvement. GW recharge rates and changes in GW quality are influenced by many factors such as soil type, soil permeability, local hydrogeology, heterogenicity, topography, land use, and management practices including GW pumping, and climatic conditions (Ramaiah et al., 2017). Very few studies investigated the effect of GW recharge through surface tanks in India on GW levels and quality (Nandanwar et al., 2020; Siva Prasad and Venkateswara Rao, 2018; Patil et al., 2017; Packialakshmi et al., 2015; NEERI, 2015). There is a lack of quantitative information in the literature on recharge rates in hard aquifers, effect on GW quality, and agricultural impact, especially for crystalline aquifers characterized by hard rock with fractured gneiss, granites, schists, and highly fractured weathered rocks of peninsular India. This study fills this gap and provides valuable insights into the effectiveness of large-scale water recycling in rural areas.

Recently, India has started large-scale recycling (Koramangala-Challaghatta valley project) of 440 million liters per day (MLD) of secondary treated wastewater (STW) based on SAT method (unlined and no wet/dry cycle) in Kolar district of Karnataka India. Kolar is a semi-arid drought-prone region with a normal annual rainfall of 650 mm for the period 1981 to 2010 (GoK, 2016; CGWB, 2009; KSNDMC, 2009). Kolar district had approximately four thousand unlined cascading man-made tanks or water reservoirs for capturing rainwater and were used for various purposes along with GW recharge (Engberg-Pedersen, 2011). With little or no rains over the last 10 years, numerous tanks and borewells had gone dry and the GW table declined at alarming levels due to over-exploitation (CGWB, 2020). The depth of irrigation borehole wells had reached ~250–300 m from the surface (Garg et al., 2020). Thus, to provide relief to the droughts, for effective management of the limited GW resources, and to ensure its long-term sustainability, in 2018, the Minor Irrigation and Groundwater

Table 1
Summary of SAT based groundwater recharge studies.

Sl. No.	Country	Climate	Soil type	Aquifer type	Wet/dry ratio	GW recharge rate (mm/day)	Impact on GW quality	Remarks	Reference
1.	Israel	Arid-semiarid	Sandy loamy	Sandy	0.5	13.3	• 70 % removal efficiency for TSS, COD, BOD, ammonia, nitrogen, phosphorous, and turbidity • 100 % removal of Coliform	• Recharged water: a reliable source of irrigation	Icekson-Tal et al., 2003
2.	Egypt	Dry-deserted	Sandy	Unconfined	0.5	25–35	• COD reduction by 95 % • BOD reduction by 70–80 %	• Constant hydraulic rate increases recharge rate by 40 %	El Arabi and Dawoud, 2012
3.	South Africa	Arid-semiarid	Sandy loamy	Sandy	–	26	• Not reported	• The numerical model MODFLOW for groundwater flow and contaminant transport	Jovanovic et al., 2017
4.	Australia	Semiarid/desert	Sandy-clay	Alluvial	0.33	107	• Improvement in recharged water quality in terms of EC, OC, TN, and $CaCO_3$	• Infiltration rates per basin varied from 0.1 to 1 m/day	Barry et al., 2017
5.	Belgium	Maritime	Sandy	Dune (saline)	–	110	• Improved water quality in terms of EC, TOC, hardness, chlorides, nitrates, phosphates, and heavy metals. Absence of total coliforms and pathogens.	• A unified conceptual model was developed, making a framework for forecasting long-term groundwater sustainability	Van Houtte and Verbauwhede, 2012
6.	Phoenix (USA)	Dry-deserted	Sandy	One layer, alluvial	0.75	Not reported	• Reduction in N by 65 %, faecal coliform by 99 %, TOC by 93 %	• Hydraulic loading rate 60–100 m/yr	Crites et al., 2014; Bauwer H., 1991

Development Department of the Government of Karnataka implemented large-scale recycling to fill 137 of these tanks with 440 MLD of STW coming from two sewage treatment plants (STPs) of Bangalore, (Manisha et al., 2023). The recycling was aimed to improve the GW table and GW quality by storing water in the existing tanks (Manisha et al., 2023; Singh, 2020). To the best of author's knowledge, there are no such large-scale full-fledged field implementation studies available in India wherein STW coming from major urban cities is used for the rejuvenation of existing surface tanks and subsequently facilitating indirect GW recharge in the semiarid drought-effective rural district. Hence, for the first time, this work (i) quantifies the GW recharge rates in the crystalline aquifers of peninsular India, characterized by hard rock aquifers with fractured weathered rocks using AMBHAS 1D GW modelling. (ii) Changes in GW quality due to the additional recharge from this project are also quantified, along with the impact on agriculture, fisheries, and milk production. (iii) Additionally, the social impacts of the improved GW table are quantified by comparing areas receiving STW to those not receiving it.

2. Methodology

2.1. Study area and design of large-scale recycling

Kolar district lies between north latitude 12° 45′ 54″ to 13° 35′ 47″ and east longitude 77° 50′ 29″ to 78° 35′ 18″ (CGWB, 2012; 2009) (Fig. 1). It has a total area of 3979 sq. km with a total population of 1,536,401(Census India, 2011). Kolar district falls under a partial rain shadow zone, and due to the topography and physiography, there are no perennial sources (rivers) of water. The soil is distributed in the range of red loamy to red sandy and lateritic soil (CGWB, 2020; DEIAA, 2019). Kolar predominantly has fractured multi-aquifer systems with gneiss/granite/schist rocks (GoK, 2016). Bedrock is peninsular gneiss of the archean age and the area can be classified as "hard rock terrain" (CGWB, 2020) with a semiarid climate. Nearly 60 % of the geographical area in the district is under agriculture which has a high-water demand (CGWB, 2020; DEIAA, 2019).

The recycling of STW in Kolar district was initiated in March 2018 (Manisha et al., 2023). The STW from Bangalore STPs is lifted and pumped first to Lakshmisagara tank (LT) of Kolar district which travels a distance of 53 km in closed channels. The water from this tank flows by gravity in open channels for a distance of 2 km to the Narsapura tank (NT) and from this tank, it flows from several ridge points to the rest of the other tanks including Kolar tank (KT). Kolar region has a network of cascading tanks that are connected by open channels. If the water level in an upstream tank exceeds its overflow weir, the excess water will flow into a downstream tank through these open channels, driven by natural gravity. These tanks are grouped into a total of 12 clusters based on their location and water flow network (a detailed plan of the recycling scheme and cluster classification along with the tank names is provided in Appendix A as Fig. A1 and Appendix B as B1 as the supplementary data). Only four pumping stations are installed in uphill areas where a gravity-based flow was not possible.

2.2. Secondary treated wastewater and surface tank water

STW samples were collected from the STP's outlet and stored at 4 °C in a refrigerator, before analysis. A detailed physio-chemical and microbiological analysis was carried out to estimate the water quality using standard methods for water and wastewater characterization (APHA, 2005). To analyse the overall impacts of this recycling, two surface tanks namely i) NT and ii) KT were selected as model tanks to represent 137 tanks. The tanks selected in the study were identified as having received STW at the start of the recycling. The NT was 2 km away from the very first tank i.e., LT whereas the KT was 16 km away from the NT (Fig. 2). A detailed water quality analysis as per the Hon'ble National Green Tribunal (NGT)

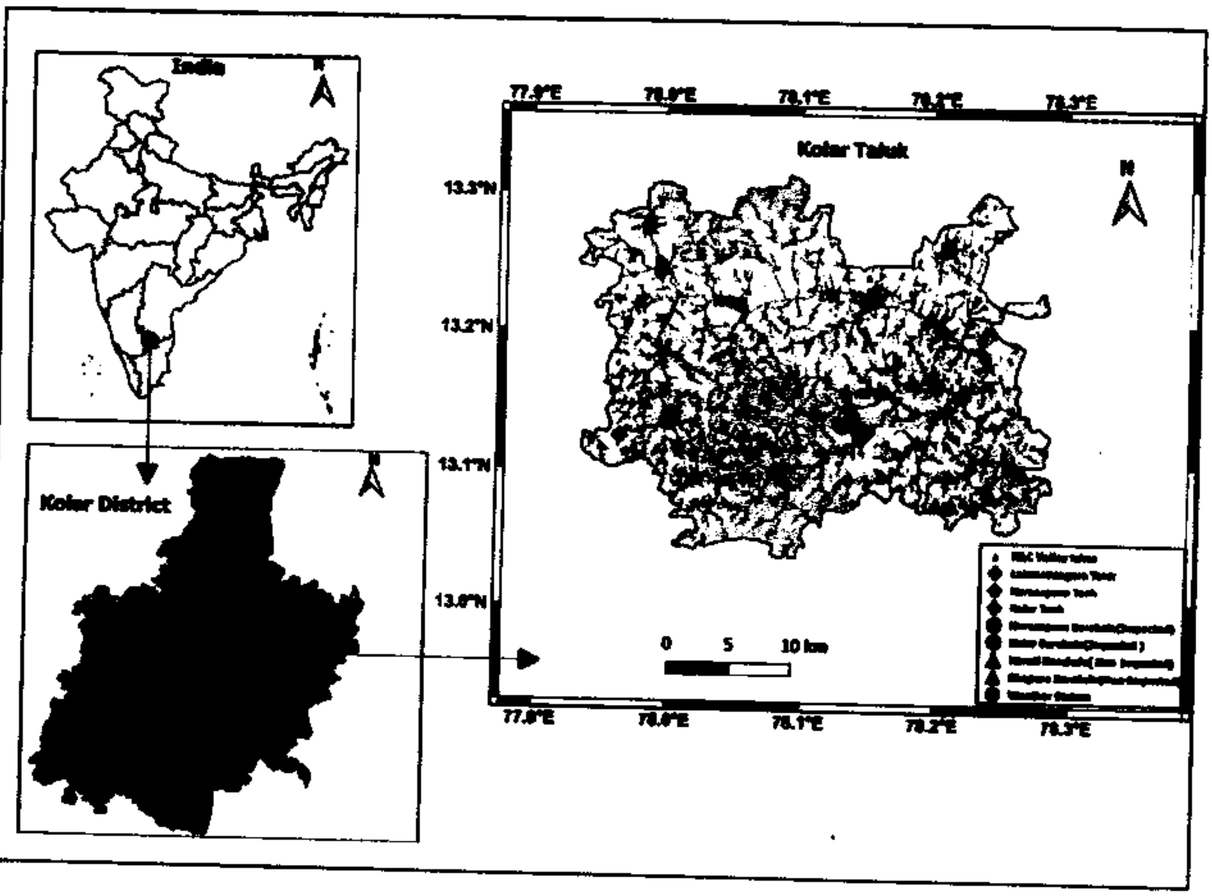

Fig. 1. Study area.

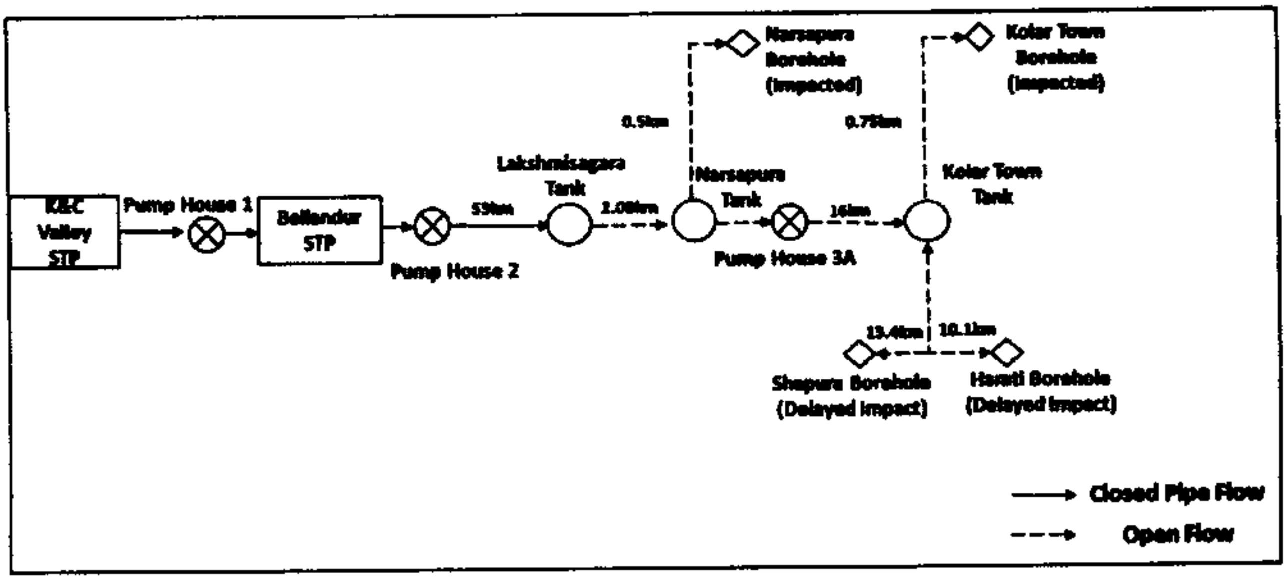

Fig. 2. Surface tank and groundwater sampling points.

standards (NGT and National Green Tribunal, 2019) which includes the specific eight parameters pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (NH_4-N), total nitrogen (TN), phosphate phosphorus (PO_4-P), and faecal coliform was performed for the STW and surface water tanks. All the water samples were tested in triplicates and average values are represented with standard deviation as avg. ± std. dev. Other than the NGT parameters a detailed analysis for heavy metals and up to 10 emerging contaminants was also carried out for the STW and surface water of the first tank (LT) receiving the treated water. ICPMS (Quadrupole ICPM- Thermo X series II) that can operate in both analog and pulse counting modes (Awual and Hasan, 2015) was used for heavy metal analysis, and LCMS (Dionex Ultimate 3000 (Thermo), micro-LC equipped with C18, 150 × 4.6 mm, 5 μm reversed phase column for the analysis of emerging contaminants. The instrument sensitivity ranges between <10 ppb to <1 ppt (parts per thousand).

2.3. Groundwater

2.3.1. Sampling and characterisation

To study the impact of indirect GW recharge using STW on GW quality two boreholes namely i) Narsapura (NB) and ii) Kolar town (KB) which were in the vicinity of the two selected surface tanks (NT and KT) were identified and designated as "impacted" boreholes. NB was 0.5 km from NT and KB was 0.75 km away from KT (Fig. 2). Similarly, two boreholes i) Shapura (SB) and ii) Harati (HB) were around 10–14 km away from one of the impacted tanks KT, were also sampled and was designated as delayed impact. The GW samples were collected and analysed following the standard methods (APHA, 2005) for their physio-chemical constituents such as pH, hardness, total dissolved solids (TDS), and electrical conductivity (EC). Calcium (Ca^+) and sodium (Na^+) as important cations, chlorides (Cl^-), and nitrates (NO_3^-) as anions, (Awual, 2016). Other water quality parameters such as magnesium (Mg^+), potassium (K^+), sulfate (SO_4^{2-}), and fluoride (F^-) were also measured using standard methods.

2.3.2. Historical groundwater level and water quality data

Historical data of GW levels and GW quality was collected to analyse the impacts of indirect GW recharge using STW. GW levels data was collected from the Karnataka Ground Water Authority (KGWA), and GW quality data from KGWA, the Central Ground Water Board (CGWB), and Karnataka State Pollution Control Board (KSPCB), Government of Karnataka for 2013–2021. These agencies are known to regularly monitor boreholes in terms of water levels and water quality.

2.4. Precipitation data

Historical monthly precipitation data (2013 to 2022) of Kolar district was collected from Karnataka State Natural Disaster Monitoring Centre (KSNDMC) to find out the rainfall pattern in the study area. Precipitation data helped to confirm the drought conditions in the study area and helped to justify the impact of recycled water on the studied GW levels and quality.

2.5. Groundwater modelling

Measurements of GW level fluctuations in response to precipitation events can provide a practical means of estimating temporally and spatially variable GW recharge rates. Lumped unconfined aquifer models have been widely applied for studying the GW dynamics and recharge estimation in the hard rock aquifer regions of southern India (Collins et al., 2020; Subash et al., 2017; Marechal et al., 2006). Park and Parker (2008) proposed an equation for modelling GW level fluctuations in response to rainfall considering the recharge and discharge terms, however, it lacked a representation of GW pumping. Subash et al. (2017) and Kumar (2016) added the GW pumping term to the equation and developed the AMBHAS_1D model with the equation (Eq. (1)) given as:

$$\frac{dh}{dt} = -\frac{1}{Sy}\lambda h + \frac{r_f}{Sy}R - \frac{1}{Sy}D_{net} \quad (1)$$

In the above equation, h represents the hydraulic head (L), Sy is the specific yield of the aquifer system (−), λ is the discharge constant (T^{-1}), R is the rainfall (LT^{-1}), r_f is the recharge factor (−) and D_{net} is the net groundwater draft or pumping (LT^{-1}).

2.5.1. Parameter estimation

Sy and r_f are two key parameters of the model which govern the GW levels. During the calibration, the reliability of simultaneous estimation of both the parameters can be improved if enough redundancy of GW time series is considered. A sequential two-step method for estimation of Sy and r_f is adopted with a GW time series of 5 years as suggested by Sekhar et al. (2013). To separate the impact of the recycling on the parameter estimation, the period from 2013 to 2017 is selected. The ranges of specific yield and recharge factors are taken from previous studies in the hard-rock aquifer region of southern India (Goswami and Sekhar, 2022a, 2022b; Garg et al., 2020; Sekhar et al., 2013). Average net GW pumping of 150 mm/year is considered for the entire simulation period (Garg et al., 2020). The recharge factor r_f estimated in this step is averaged over the 5-year duration which is representative of a fraction of rainfall that gets converted into recharge.

2.5.2. Recharge estimation

For the estimation of recharge, Sy is kept as estimated in the previous step. Net GW pumping is kept at 150 mm/year to maintain consistency. The model estimates monthly total recharge (R_T) by minimizing the sum of the square of the error between the observed and simulated GW level from 2013 to 2021. The recharge from rainfall (R_P) is obtained by multiplying the r_f by the monthly rainfall time series. Recharge from the tank (R_L) is calculated by subtracting R_P from R_T.

2.6. Impact on land use land cover (LULC) and agricultural activities

In addition to the impacts on GW levels and quality, the present study also focuses at impacts of recycled water on land use land cover change (LULC), agricultural productivity, milk production, and fishery status specifically in the study area. A comparative analysis was carried out between the impacted area of Kolar district which receives recycled water (Narsapura village) and the non-impacted area (Nelavenki village) which is 63 km away from the impacted study area and has not received recycled water. To study the impacts required data was collected from different government organizations like LULC data from Environmental Systems Research Institute (ESRI, 2017–2022), agriculture data for the year 2021–2022 from the Department of Agriculture & Horticulture Kolar, milk production data (2021 – 2022) from Kolar district co-operative milk producer's societies union, and fishery data (2021–2022) from the Department of Fishery Sciences, Kolar to carry out this analysis.

3. Results and discussion

This section presents the analysis of the impacts of STW recycling for indirect GW recharge on the surface water quality, GW levels including GW modelling, GW quality and agricultural sectors.

3.1. Water quality analysis of secondary treated wastewater and surface tank water

Table 2 represents the water quality of the STW coming from STP and surface tank water identified for the study. The test results were compared with the NGT standards.

As the STW is pumped into the tanks, assessing the water quality in these tanks is important which represents the health of the tank. As can be seen from Table 2 the STW coming from the STP meets all the norms set by the NGT (2019) for the treated wastewater to dispose into surface water bodies or for land disposal/applications except for faecal coliform levels, which was slightly above the standard. It is known that such microbial population will reduce rapidly when water flows through multiple tanks and more so during infiltration through soil column to reach the GW (Grinshpan et al., 2021). As per NGT norms pH should range from 6.5 to 9 as most aquatic organisms prefer this as the acidic nature of water (pH < 7) enhances the proliferation of algae (Bergstrom et al., 2007; Leavitt et al., 1999). The BOD and COD predominantly represent the rapidly decomposable and more recalcitrant organic loads in the treated water and thus should not exceed 10 and 50 mg/L respectively (NGT, 2019; Zhang et al., 2018). The marginal change of COD/BOD in waters of LT and KT in spite of having undergone many days of flow, indicate that these values are stable and do not represent decomposable organics and is more likely from inorganic sources. The discharge limits for TN is <10 mg/L and PO_4- P is <1 mg/L which is meant to restrict autotrophic algal growth (leading to algal blooms), if it is in excess can sometimes lead to hypoxia at pre-dawn hours from excessive algal respiration and resultant fish death (Abu et al., 2022; Mishra et al., 2022; Yaqub et al., 2022; Alidina et al., 2014). The TSS values were lower than the discharge limit of 10 mg/L. A low TSS in the receiving waterbody indicates completeness of the treatment system.

Table 2 also presents the water quality of the first tank (LT) receiving the STW. It can be observed that the water quality in the LT has slightly improved relative to STW. The marginal improvement in water quality between the STW and its receipt at LT is suggestive of a small role of the nearly 22-h residence time for treated water to travel 53 km through pipes and its contribution to improved water quality.

As discussed earlier in Section 2.1 the STW received first at LT, remains there for a significant period before flowing 2.1 km through open channels, and passing through two more surface tanks before reaching the NT. Ideally, the NT's water quality should have improved relative to LT, due to natural treatment from flow in open channels and residence time in surface tanks. However, as shown in Table 2, it was observed that the water quality of the NT has marginally deteriorated, likely due to human activities such as fertilizer runoffs from agricultural land and fugitive discharges of domestic sewage by houses on the tank shore.

When the overflow from the NT travels to the KT by covering a distance of 16 km, while also spending a large residence time in open tanks, it can be observed that the water quality of the KT has improved relative to the NT. It is indicated that in addition to the long periods of residence time spent by STW during its flow through a cascade of surface water tanks as well as through the connecting water channels, this treated water is subjected to a long residence time within the tanks that it passes through which leads to natural treatment. The water quality of KT when compared with that of the STW, it was observed that there was almost 25 to 50 % improvement. Such an observation where the treated water encounters multiple treatment opportunities but still show small changes in quality indicates that the treatment systems are functioning to their near ideal levels and leave behind very little treatable substances. The presented results are supported by Amin et al. (2022); CGWB, (2020); Sharma and Kennedy (2017) where the water quality of treated water improved due to the self-purification mechanism in the flowing state and through dilution as an impact of GW recharge. Eslamian et al. (2018) reported the removal of dissolved organic compounds during GW recharge through SAT system as an impact of microbial biodegradation and absorption. El Arabi and Dawoud (2012) reported the removal of suspended solids, biodegradable materials, bacteria, and other microbes from treated wastewater through the vadose zone as it

Table 2
Water quality of secondary treated wastewater and surface tank water.

Sl. No.	Parameters	Unit	Hon'ble NGT discharge standards (NGT, 2019)	Sampling points			
				STW from outlet of STP	Lakshmisagara tank (LT)	Narsapura tank (NT)	Kolar Town tank (KT)
1.	pH	–	6.5–9.0	7.6	7.6	7.8	7.7
2.	BOD_5 (@20 °C)	mg/L	10	9 ± 1.0	6.2 ± 1.5	7.2 ± 2.0	6.4 ± 1.4
3.	COD	mg/L	50	48 ± 4.0	42 ± 8.0	50 + 4.0	42 ± 2.0
4.	TSS	mg/L	10	8 ± 2.2	6.8 ± 2.0	7.2 ± 2.8	6 ± 1.5
5.	NH_4 -N	mg/L	5	4.6 ± 0.8	3.7 ± 0.3	2.8 ± 0.8	2.4 ± 0.2
6.	TN	mg/L	10	7.8 ± 2.5	5.3 ± 1.4	6.9 ± 1.0	5.2 ± 0.8
7.	PO_4- P	mg/L	1.0	0.8 ± 0.3	0.3 ± 0.1	0.6 ± 0.2	0.4 ± 0.1
8.	Faecal Coliform	MPN/100 mL	< 230 allowable	280 ± 20	220 ± 16	240 ± 30	230 ± 25

Table 3
Heavy metal analysis of secondary treated wastewater and first surface tank.

Sl. No.	Metals, metalloids, and heavy metals	IS 10500 (mg/L) (BIS 10500, 2012)	Secondary treated wastewater (mg/L)	Lakshmisagara tank (LT) (mg/L)
1	Iron (Fe)	3	0.36 ± 0.02	0.26 ± 0.001
2	Manganese (Mn)	2	0.02 ± 0	BDL ± 0
3	Zinc (Zn)	5	BDL ± 0	BDL ± 0
4	Cadmium (Cd)	2	BDL ± 0	BDL ± 0
5	Lead (Pb)	0.1	BDL ± 0	BDL ± 0
6	Arsenic (As)	0.2	0.001 ± 0	0.001 ± 0
7	Chromium (Cr^{+5})	0.1	<0.1 ± 0	<0.1 ± 0
8	Nickel (Ni)	3	0.028 ± 0	0 ± 0
9	Copper (Cu)	3	0.00 ± 0	0 ± 0
10	Aluminium (Al)	0.2	BDL ± 0	0 ± 0
11	Barium (Ba)	0.7	0.045 ± 0	0.01 ± 0
12	Boron (B)	0.5	0.021 ± 0	0.001 ± 0
13	Selenium (Se)	0.01	BDL ± 0	BDL ± 0
14	Silver (Ag)	0.1	BDL ± 0	BDL ± 0
15	Mercury (Hg)	0.001	BDL ± 0	BDL ± 0
16	Molybdenum (Mo)	0.07	0.001 ± 0	BDL ± 0

Note: BDL is below the detection limit of 1×10^{-6} mg/L.

acts as a natural filter in SAT systems. Wilson et al. (1995) reported 50 % removal of nitrogen, heavy metals, and disinfection byproducts through the vadose zone.

Table 3 represents the water quality in terms of heavy metals. As can be seen from Table 2, the STW and LT's water meets even the stricter standards for drinking water (BIS 10500, 2012) for heavy metals. This suggests two possibilities: firstly, there is very low contamination of urban runoffs, and secondly, the anaerobic stages experienced by wastewaters generally cause heavy metals to precipitate and separate out, even if they are present (Manisha et al., 2023; Rao et al., 2021; Awual et al., 2020; Awual, 2019). Therefore, from this perspective, the wastewaters are rendered safe for discharge to surface water bodies. El Arabi and Dawoud, 2012 reported the removal of heavy metals and other inorganic contaminants from wastewater during GW recharge as an impact of geochemical reactions such as mineral precipitation, dissolution, adsorption, and redox reactions.

Detailed studies on the presence of emerging contaminants in STW and surface water in the study area are underway. Preliminary results presented in Table 4 indicate their absence in STW and subsequently in the first surface tank (LT) receiving STW. This is because the STW undergoes different levels of natural treatment as it experiences a long residence time (>14 days) in tanks (Manisha et al., 2023; Teo et al., 2022; Icekson-Tal et al., 2003).

The rejuvenated tanks are home to a variety of birds, such as fish eagles, herons, and various types of ducks, indicating the presence of a large fish

Table 4
Summary of emerging contaminants in secondary treated wastewater and surface tank.

Sl. No.	Test parameter	Type	Secondary treated wastewater (mg/L)	Lakshmisagara tank (LT) (mg/L)
1	Fluoroquinolones	Antibiotics	BDL	BDL
2	Ciprofloxacin		BDL	BDL
3	Azithromycin		BDL	BDL
4	Tetracycline		BDL	BDL
5	Norfloxacin		BDL	BDL
6	Acetaminophen	Pain killers	BDL	BDL
7	Ibuprofen		BDL	BDL
8	Diclofenac		BDL	BDL
9	Sulfamethoxazole		BDL	BDL
10	Cetirizine		BDL	BDL
11	Xylenol	Pharmaceutical and personal care products	BDL	BDL
12	Triclosan		BDL	BDL

Note: BDL is Below detection limit (< 0.001)].

population, which serves as their primary food source. Large and smaller fish were also observed in these tanks, starting from the LT, indicating successful breeding. These observations suggest that the recharged water quality is suitable for aquatic life and supports fish growth and reproduction, which was previously a concern when selecting fish for commercial cultivation in these tanks. In the past, it was challenging for fish to breed in what was perceived as "hard/polluted" water. However, these observations demonstrate that the approach of recharging water in the tanks allows for successful fish breeding and growth, eliminating the need for separate breeding programs and seeding with fingerlings. These observations, showing fish in various stages of breeding and growth, clearly indicate the suitability of this approach not only for fish cultivation but also for their breeding and the long-term sustainability of surface tank water.

3.2. Impact on groundwater levels

Fig. 3 (a) and (b) represents the historical data for GW levels and precipitation of impacted as well as non-impacted boreholes of Kolar district.

It can be observed from Fig. 3 that the GW levels before recycling STW (March 2018) were around 18 mbgl (meters below ground level) which improved to 7.5 mbgl for NB and for KB it was 33 mbgl in Aug 2018 which rose to 9 mbgl in September 2018. A clear immediate positive impact on GW levels can be observed as the levels increased by 58 % and 73 % respectively in the studied impacted boreholes. Literature reports a linear relationship between GW recharge and rainfall (Rasel et al., 2023; Anuraga et al., 2006) but it can be observed from the historical precipitation data (KSNDMC, 2020) represented in Fig. 3 that 2018–2019 was a rain deficit period but still the GW levels increased which confirms direct impact of recycled water (STW) filled in the existing surface tanks near to the studied boreholes. This clearly has resulted because surface water from rejuvenated tanks has infiltered through soil layers and percolated vertically downward deep in the soil through the unsaturated zone towards the water table. The movement of water also depends on soil permeability or hydraulic conductivity. Pore space in the soil serves as the storage compartment for water. It is reported that the Karnataka state is underlain by peninsular gneisses, and granites (Ramaiah et al., 2017). The studied surface tanks are also located at such highly fractured and weathered rock and have a sufficient thickness of permeable vadose zone which helps for speedy GW recharge (Veeranna and Jeet, 2020; DEIAA, 2019; Asano and Cotruvo, 2004). Fig. C (a) (Appendix C) represents maps showing low water levels in Kolar district before commencement of the recycling and Fig. C (b) represents increased water levels after commencement of the project.

As discussed in Section 2.1 soil type in Kolar district ranges from red loamy soil to red sandy lateritic soil which is also characterized by low water holding capacity and increased hydraulic conductivity (GoK, 2016; Sivapullaiah et al., 2003). This soil has an infiltration rate of >10 in. per hour (CGWB, 2020) thus an immediate response can be seen in the impacted boreholes which were in the nearby vicinity of the rejuvenated surface tanks. Thus, it can be concluded that indirect artificial recharge of the GW has a significant role in the development and management of drought-prone semi-arid areas as it boosts the GW level. Nandan et al. (2021); Shawaqfah et al. (2021); Dillon and Arshad (2016); El Arabi and Dawoud (2012); and Icekson-Tal et al. (2003) also reported improved GW levels through indirect GW recharge methods.

Fig. 3 (c) and (d) represents water levels of two boreholes (SB and HB) with delayed impact where it can be observed that in both the boreholes there is no immediate improvement in the GW levels post recycling. It is thus concluded that treated water has not reached to these areas which are far away (at a distance of 10 to 14 km from the KT) until 2020. Whereas it can also be observed that the water levels have increased in both SB and HB after 2020. At SB, the water level increased by 80 % from October 2021 to November 2021 whereas at HB it increased by 48 % from October 2020 to November 2020. This is attributed to the fact that these two boreholes have shown a delayed impact with respect to 2018 post recycling and may be attributed to lateral movement of percolated underground water

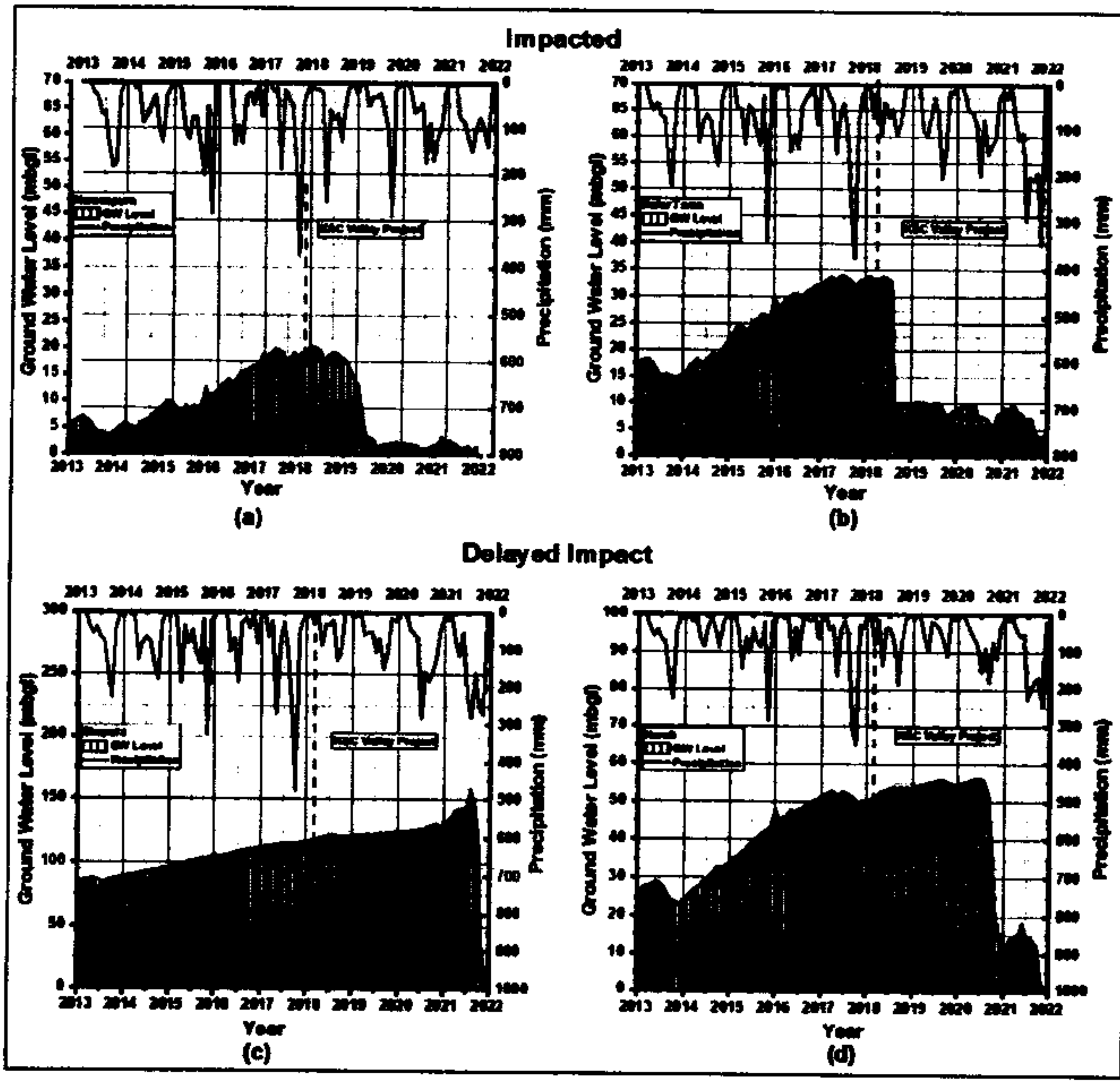

Fig. 3. Change in groundwater levels between before and after recycling of secondary treated wastewater for impacted boreholes (a and b) and non-impacted boreholes (c and d) Source: Precipitation data from KSNDMC and GW water level from KGWA and CGWB.

over a long period. To order to confirm these findings GW modelling was carried out.

3.3. Groundwater modelling

As discussed in Section 2.5 a physically lumped unconfined model AMBHAS_1D was used to model the GW level fluctuation in two steps considering the GW recharge, discharge, and pumping. In the first step model calibration was carried out for a period of 5 years from 2013 to 2017 during which the GW levels were representative of long-term GW balance in the non-impacted region. The estimated set of parameters along with performance indices "Root Mean Squared Error" (RMSE) and "Coefficient of determination" (R^2) are listed in Table 5. Fig. 4 represents the comparison of simulated and observed GW levels for the calibration period. In the second step, the calibrated set of aquifer parameters were forced into the model to estimate the monthly recharge values corresponding to the best fit between observed and simulated GW levels from 2013 to 2021.

Fig. 5 represents the estimated monthly recharge and the simulated GW level time series for 2013–2021. The monthly recharge estimates are validated by comparing the model simulated GW levels with observed GW tanks in terms of R^2 and RMSE (Goswami and Sekhar, 2022a, 2022b; Sekhar et al., 2013. In Fig. 5, blue and green bars correspond to the recharge from rainfall and tanks respectively. As discussed in Section 3.2 the two impacted boreholes reflect good GW recovery just after recycling was started in March 2018. The other two boreholes SB and HB, showed a delayed GW

Table 5
Estimated parameters and performance of the model calibration.

Sl.No.	Boreholes	RMSE (m)	R^2	rf	Sy
1	Narsapura (NB)	2.8	0.7	0.127	0.05
2	Kolar (KB)	3.22	0.77	0.094	0.039
3	Shapur (SB)	3.61	0.88	0.124	0.018
4	Harati (HB)	3.97	0.85	0.099	0.025

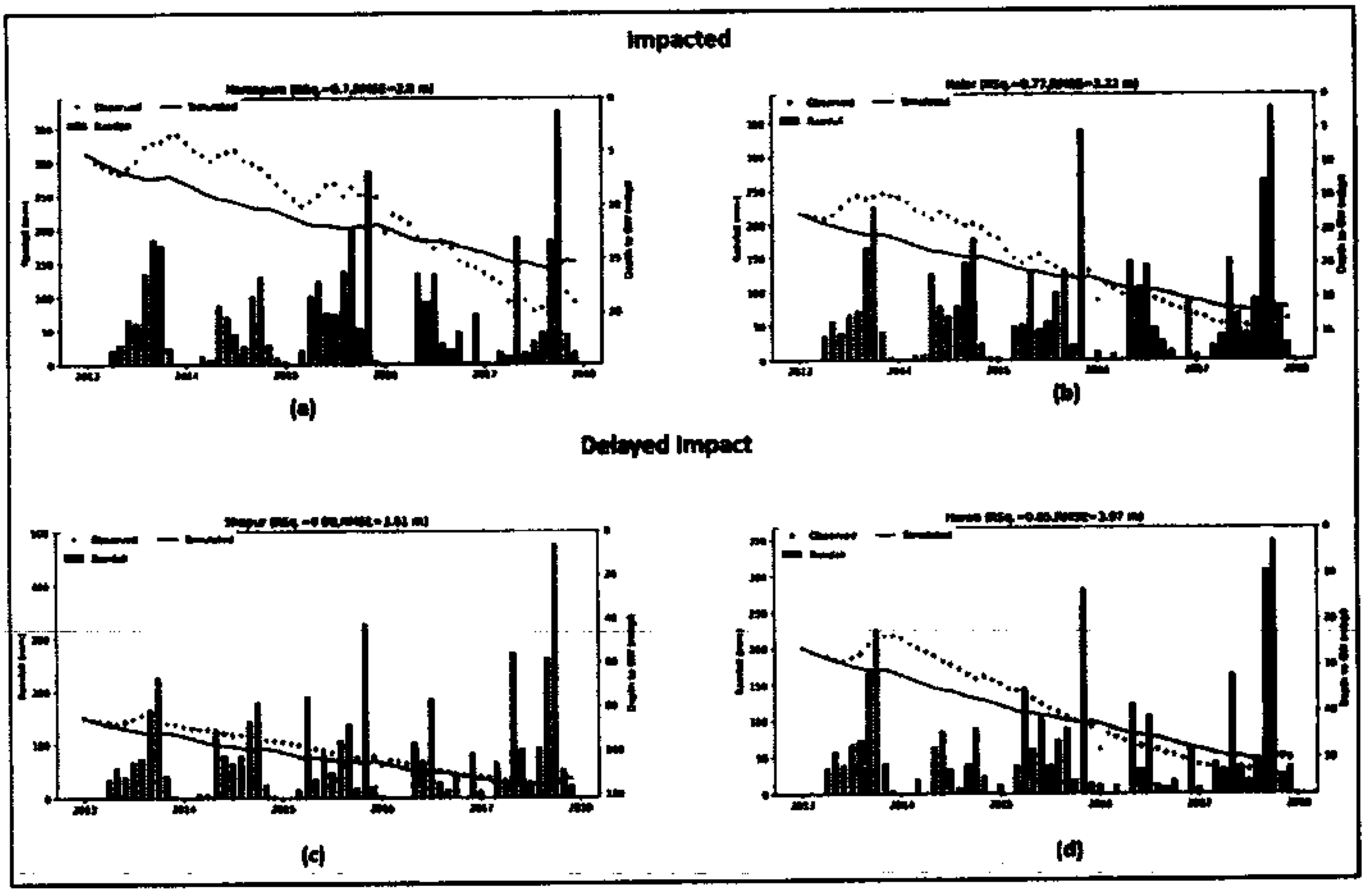

Fig. 4. Comparison of simulated and observed GW levels for calibration period (2013–2017).
Source: Precipitation data from KSNDMC and GW levels data from KGWA and CGWB.

recovery because of slow lateral movement of GW as these locations are far from the rejuvenated tanks. The annual water budget for each location is tabulated and provided in Table 6. Daily recharge rate before 2018 are in the range of 0.1 to 0.48 mm for all four boreholes studied. The daily recharge rates of NB and KB reflect the impact of recycling stating from year 2018 as the daily recharge rate is almost 2–10 times higher for 2018 and 2019. The sharp rise in the observed GW levels at impacted locations in range of 20 m to >100 m within 4–6 months duration supports the higher recharge estimates because of contribution of rejuvenated tanks. Since 2019, these two borehole sites exhibit low seasonal GW level variability (around 5 m) as these sites are in the vicinity of the tanks which act as constant head boundary condition. The other two boreholes (SB and HB), experience 5–10 times rise in daily recharge rate in 2020 and 2021 respectively confirming a delayed impact with respect to 2018. Net pumping to recharge ratio at all locations before the recycling was >1 signifying unsustainable GW pumping in the region. The daily recharge rate improved significantly post 2018 because of the extra recharge from the tanks which is much higher than the direct recharge from rainfall. The increased recharge compensates for pumping and the ratio of net pumping to total recharge drop below 1. The GW recharge estimates based on GW modelling indicate that this large scale recycling of STW has enhanced the GW recharge in the region resulting in rapid recovery of GW storage (Manisha et al., 2023; El Arabi and Dawoud, 2012; Icekson-Tal et al., 2003).

3.4. Impact on groundwater quality

Results represented in Section 3.3 confirm that STW filled in the tanks has recharged the GW table of the study area and thus this section represents its impact on GW quality as represented in Figs. 6, 7, 8 and 9.

The graphs in Figs. 6-9 illustrate that, the groundwater quality in the impacted boreholes has improved across all studied parameters when comparing the data from before and after the recycling period. Observations indicate that in the case of NB, there was no significant change in pH value. However, a notable reduction in water quality parameters was observed, including a 55 % reduction in hardness, 23 % reduction in TDS, 12 % reduction in EC, 46 % reduction in Ca+, 62 % reduction in Na^+, 22 % reduction in Cl^-, and 84 % reduction in NO_3^-. Similarly, for KB, no change in pH value was observed, but there was a significant reduction in water quality parameters, including a 70 % reduction in hardness, 76 % reduction in TDS, 85 % reduction in EC, 88 % reduction in Ca^+, 88 % reduction in Na^+, 96 % reduction in Cl^-, and 93 % reduction in $NO3^-$. Fig. D1 and D2 (Appendix D) represents reduction in Mg^+, K^+, SO_4^{2-}, and F^- when compared between before and after recycling period. Clearly the hard waters of deep aquifers (before recycling) with a lot more dissolved salts have transformed into a more agriculture friendly water (Hasan et al., 2023; Teo et al., 2022).

Figs. 6, 7, 8, and 9 highlight the dilution effect on the water quality parameters resulting from the recharge of recycled water into the deep aquifer during its infiltration through the soil. As discussed earlier, the STW held in tanks infiltrates into the subsurface and deeper aquifers rapidly, and percolates vertically through the unsaturated zone towards the water table (Saleem et al., 2016; Bekele et al., 2011). This infiltration process through the soil is slow, which results in the purification of any residual chemicals that may have escaped the wastewater treatment process. Moreover, this filtration process occurring over months starves the potential pathogens, ensuring their rapid die-off (Hasan et al., 2023; Hasan et al., 2021; Maurya et al., 2020; Islam et al., 2020).

The removal mechanisms involved in the recycling process include physical filtration, biodegradation, adsorption, chemical precipitation, ion

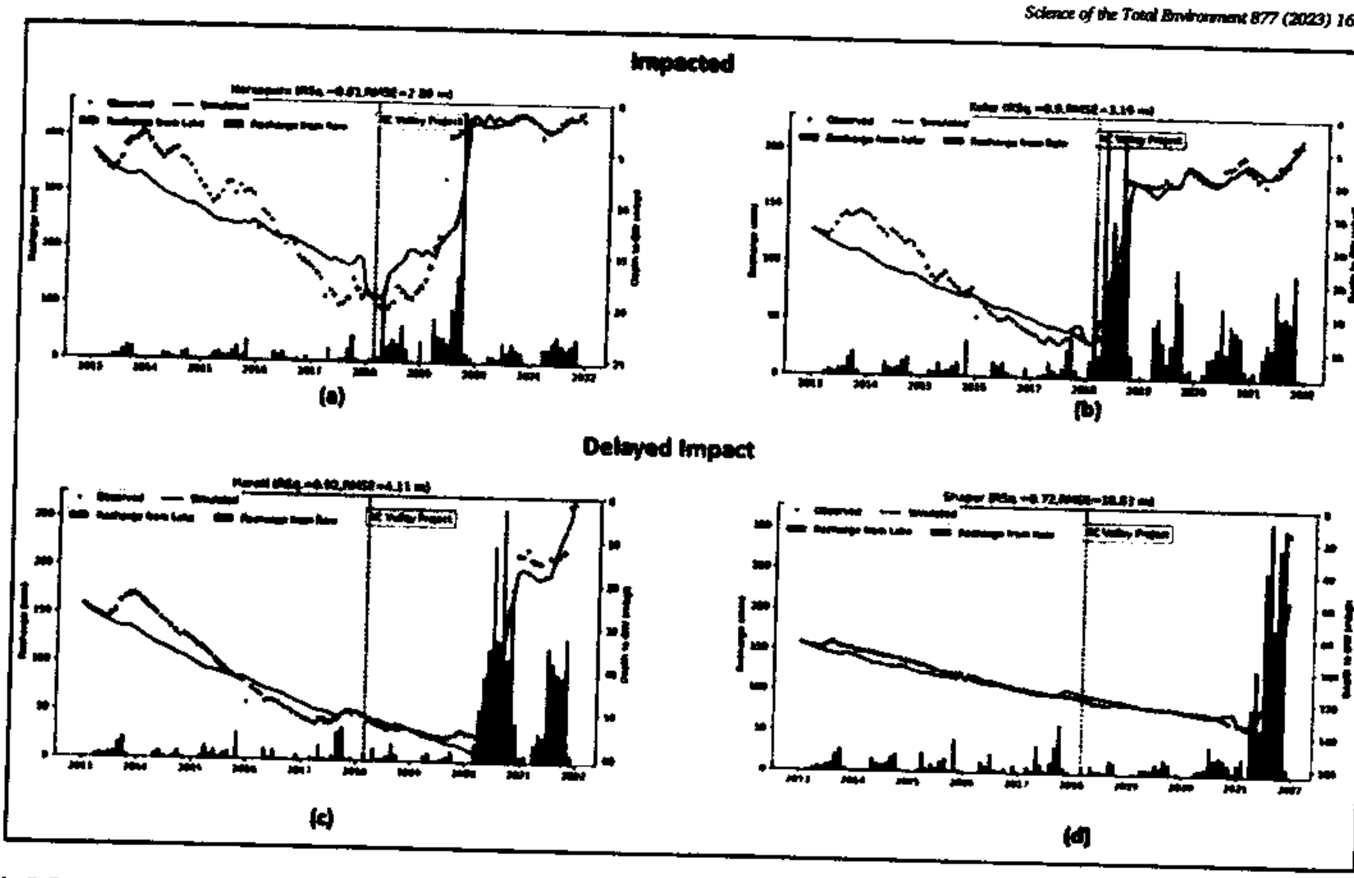

Fig. 5. Estimated monthly recharge from rainfall and tanks
Source: Precipitation data from KSNDMC and GW levels from KGWA and CGWB.

exchange, and dilution. Microbial action typically converts organic contaminants into simpler compounds, while filtration through various soil layers removes suspended matter and pathogens (Islam et al., 2021; Mazrouaa et al., 2019; Bekele et al., 2011), confirming the safety of the recharged groundwater for reuse. As shown in Fig. 6-9, the delayed impact of recycled water on groundwater recharge in SB and HB resulted in no significant impact on water quality before 2019, but a significant improvement was observed in 2020–2021 due to dilution. The results of this study are consistent with the findings of Zhang et al. (2018), who reported improved groundwater quality with a standard of class 1 WQ Index in a laboratory experimental setup using reclaimed water for groundwater recharge. El Arabi and Dawoud (2012) observed the removal of suspended solids, biodegradable substances, nitrogen, phosphorus, and heavy metals due to the vadose zone acting as a natural filter. Bekele et al. (2011) reported 66 % removal efficiency for fluoride (F^-), 62 % for iron (Fe), 51 % for total organic carbon (TOC), and 30 % for phosphorus (P) through a MAR system when treated

Table 6
Annual water budget and contribution of recharge from rain and tanks.

Boreholes	Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
	Net pumping (mm)	150	150	150	150	150	150	150	150	150
Narsapura	Total recharge (mm)	90	67	139	69	120	352	966	181	284
	Recharge from rain (mm)	90	67	139	69	120	89	80	109	109
	Recharge from lake (mm)	0	0	0	0	0	263	886	73	175
	Daily recharge rate (mm/day)	0.25	0.18	0.38	0.19	0.33	0.97	2.65	0.50	0.78
	Net pumping to total recharge ratio	1.6	2.2	1.0	2.1	1.2	0.4	0.1	0.8	0.5
Kolar	Total recharge (mm)	67	68	88	56	108	1101	358	293	429
	Recharge from rain (mm)	67	68	88	56	108	53	71	87	150
	Recharge from lake (mm)	0	0	0	0	0	1048	287	206	279
	Daily recharge rate (mm/day)	0.18	0.19	0.24	0.15	0.30	3.02	0.98	0.80	1.18
	Net pumping to total recharge ratio	2.2	2.2	1.7	2.6	1.3	0.1	0.4	0.5	0.3
Shapur	Total recharge (mm)	89	90	123	66	173	56	81	138	1647
	Recharge from rain (mm)	89	90	123	66	173	56	81	138	184
	Recharge from lake (mm)	0	0	0	0	0	0	0	0	1463
	Daily recharge rate (mm/day)	0.24	0.25	0.34	0.18	0.48	0.15	0.22	0.38	4.51
	Net pumping to total recharge ratio	1.6	1.6	1.2	2.2	0.8	2.6	1.8	1.0	0.0
Harati	Total recharge (mm)	71	37	87	39	106	65	47	1217	640
	Recharge from rain (mm)	71	37	87	39	106	64	45	84	119
	Recharge from lake (mm)	0	0	0	0	0	1	2	1134	520
	Daily recharge rate (mm/day)	0.19	0.10	0.24	0.11	0.29	0.18	0.13	3.33	1.75
	Net pumping to total recharge ratio	2.1	4.0	1.7	3.8	1.4	2.3	3.1	0.1	0.2

Source: Precipitation data from KSNDMC and GW level from KGWA and CGWB.

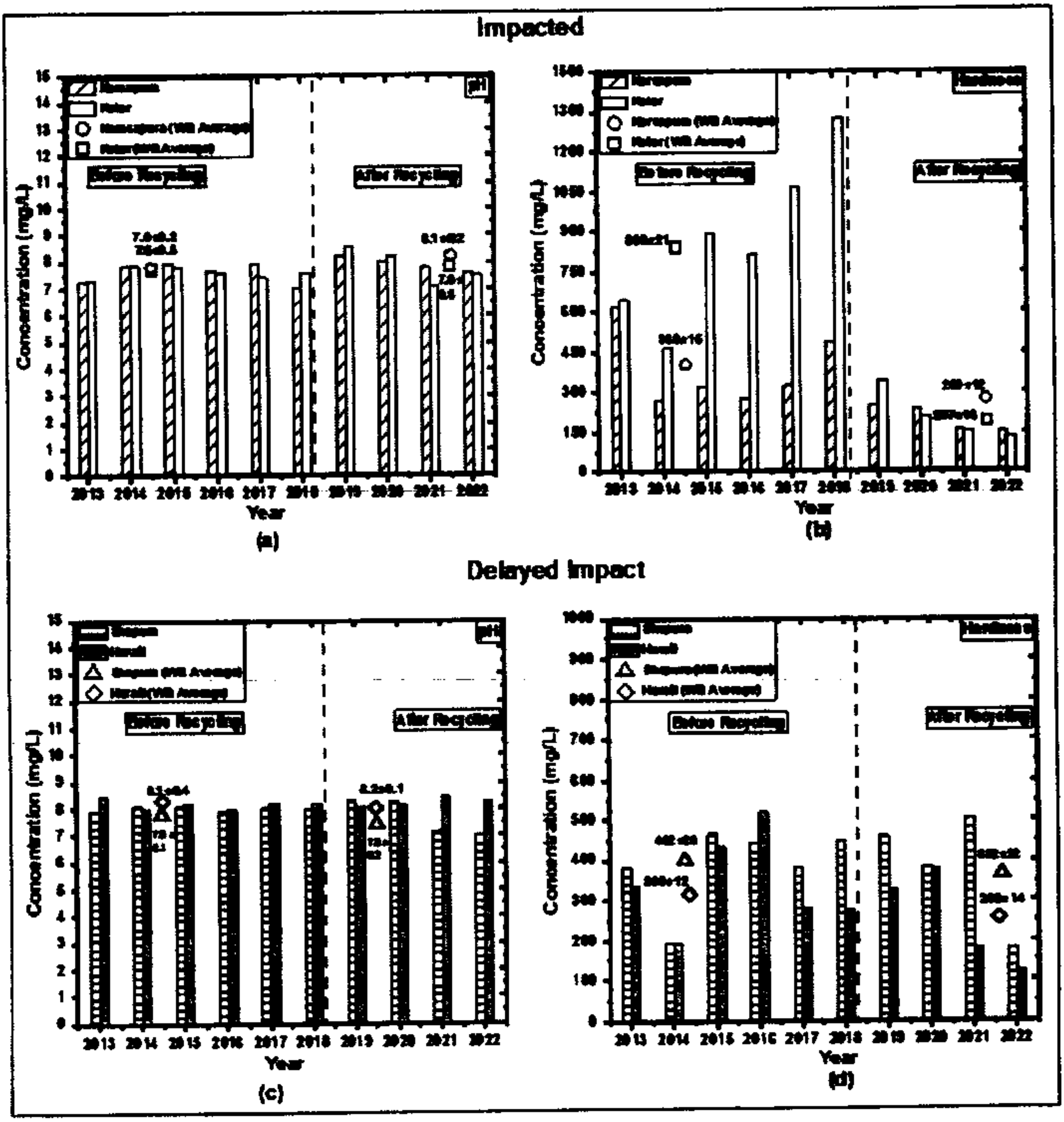

Fig. 6. Impact on groundwater quality (physio-chemical)
Source: KGWA and CGWB
Note: Before recycling period is 2013–2017 whereas after recycling period is 2018–2022.

wastewater was used for groundwater recharge. Icekson-Tal et al. (2003) reported 70 % removal efficiency for COD, BOD, and other substances through a SAT system when treated wastewater was used for groundwater recharge. Experimental studies by Bauwer, 1991 also reported reduced levels of N, TOC, sulfate, and faecal coliforms in recharged groundwater.

3.5. Impact on LULC, agriculture, milk, and fish production

Fig. 10 represents the topographic view of the impacts of using STW for indirect GW recharge on land use and land cover of impacted area. Land Use Land Cover (LULC) maps provide information to understand the current landscape (Manisha et al., 2023; Rasel et al., 2023). Annual LULC information on national spatial databases enables the monitoring of temporal dynamics of the study area where land cover is the physical material at the surface of the earth and land use is the description of utilizing the land for socio-economic activities. A significant shift in LULC was observed between 2017 and 2022 where the number of water bodies have increased by 5 times, the trees by 43 %, flooded vegetation by 67 times, cropping land by 4.2 %, built area by 43 %, whereas bare ground and rangeland decreased by 44 % and 30 % respectively which gives a clear indication of the

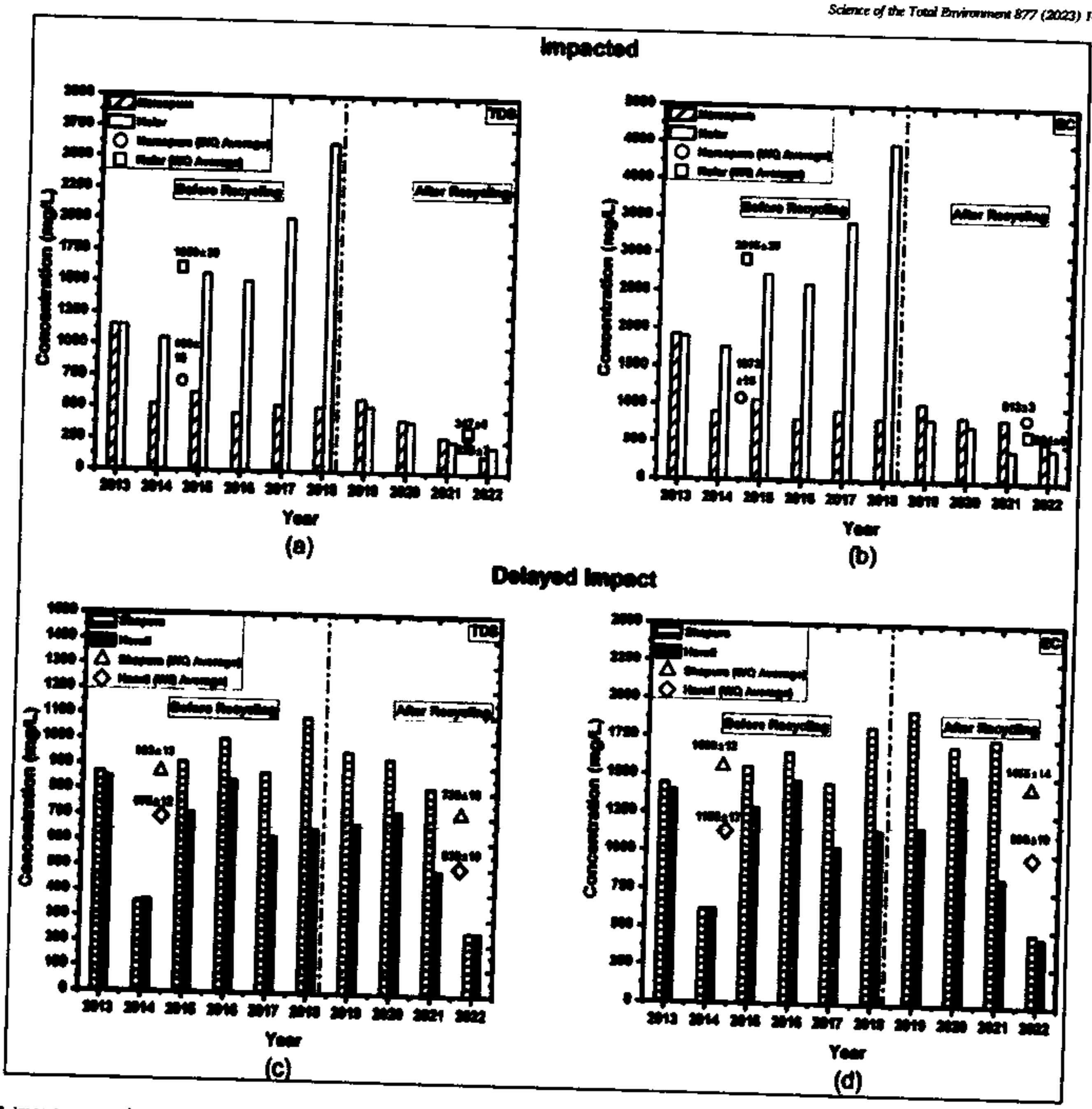

Fig. 7. Impact on groundwater quality (physical parameters)
Source: KGWA and CGWB
Note: Before recycling period is 2013–2017 whereas after recycling period is 2018–2022.

increased availability of water and brought about positive impact of K&C valley water on the LULC.

Fig. 11 (a) and (b) presents the cultivated area that is utilized for different types of crop production. It can be observed that the area utilized for crop production is more in the impacted area (Narsapura village) when compared to the non-impacted area (Nelavenki village). Significant improvement is observed in area cultivated using vegetables (80 %), cereals (35 %), plantations (38 %), flowers (100 %), fruits (57 %), and pulses (40 %). This is due to the increased access to GW which is possible to the improved GW table by K&C valley water. Similarly, significant changes in crop productivity (Fig. 10 b) are observed for vegetables (37 %), fruits (2 %), plants (13 %), cereals (11 %), and pulses (12 %). Overall, there is a positive trend in cropped area (agriculture) through the availability of indirect GW recharge which has "greened" the otherwise semi-arid and nearly desertified area. It can be attributed that previously in the study area the drought conditions have resulted in water scarcity, low in situ soil moisture and soil erosion, poor crop and livestock productivity, poor soil conditions with low organic C, nutrients such as phosphorous and zinc which are now taken care due to secure water availability. It can also be concluded that the assured availability of irrigation water throughout the year (Manisha et al., 2023; Ofori et al., 2021) and the revival of the GW table has shifted the cropping pattern from low water requiring crops (e.g., pulses, oil seed) to high water requiring and also water-intensive /water sensitive crops (vegetables, flowers, etc.).

Fig. 11 (c) and (d) represent the impact on milk and fish production in the impacted area. It can be observed (Fig. 11 c) that the quantity of milk production has improved by 33 % in the impacted area when compared with the non-impacted area due the higher observed increase in the

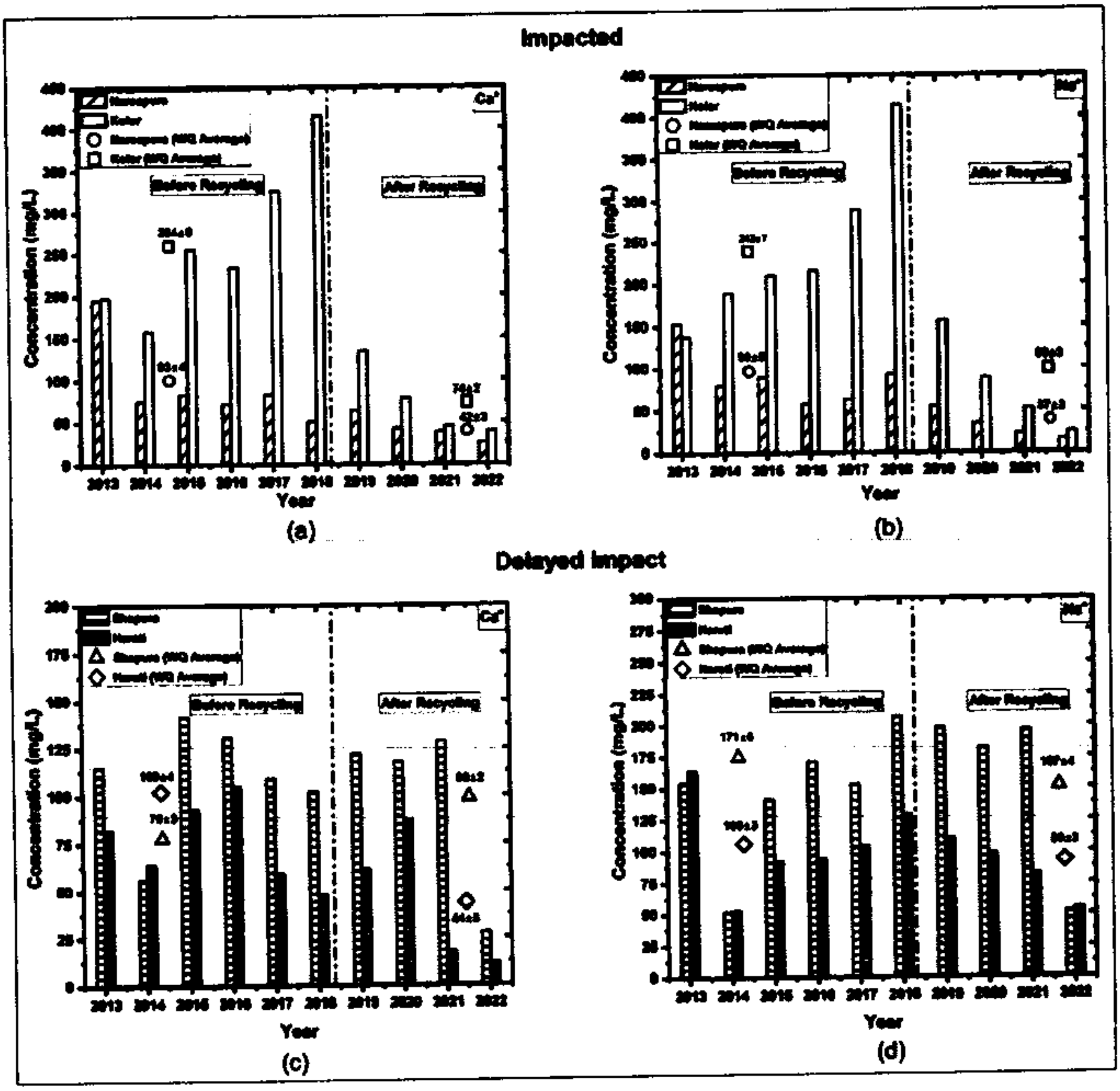

Fig. 8. Impact on groundwater quality (Cations)
Source: KGWA and CGWB
Note: Before recycling period is 2013–2017 whereas after recycling period is 2018–2022.

availability of green fodder for the animals and is also a key determinant for maintenance and viability of maintaining milch cattle (Manisha et al., 2023; Zaibel et al., 2019). It thus appears that the improved availability /reliability of water for fodder cultivation has a positive impact on livestock rearing along with milk production (although the extent of land dedicated to fodder and their yields are not reported here).

Fig. 11 (d) represents the impact of using STW in tank rejuvenation on fish production levels. During the drought conditions the fish production decreased as a result of lower water availability and perhaps a shorter growth period for the introduced fish when most of the tanks dried up rapidly. However, due to the implementation of the large scale recycling, there is year-round availability of water in the tank and the tanks are generally filled to maximum levels. It is suggested that owing to the higher reliability of the water in the tanks as well as the higher volumes of water currently stored in these tanks, the fish productivity has resulted in an increase by 341 % when compared with the non-impacted area. As mentioned earlier, there is a significant improvement in water quality, especially the hardness, because of which there is now an opportunity to raise not only larger numbers of fish but also a greater variety while also facilitating their breeding in situ.

Studies supporting the presented results (Zaibel et al., 2019), namely the assessment of the food web starting from phyto-plankton and zooplanktons, indicate that the aquatic flora (phytoplankton) and fauna (zooplankton) required to support good fish populations are present in adequate numbers in the tank water (STW). The increased availability of plankton, required nutrients such as ammonia, nitrite, nitrate, calcium, and potassium have now clearly improved and is supported by the food web analysis (not presented in this paper). Similarly, such additional nutrients are generally used for fertilization of fish ponds in aquaculture which is also a known practice around the World (Zaibel and Zilberg, 2021). Nandan et al. (2021);

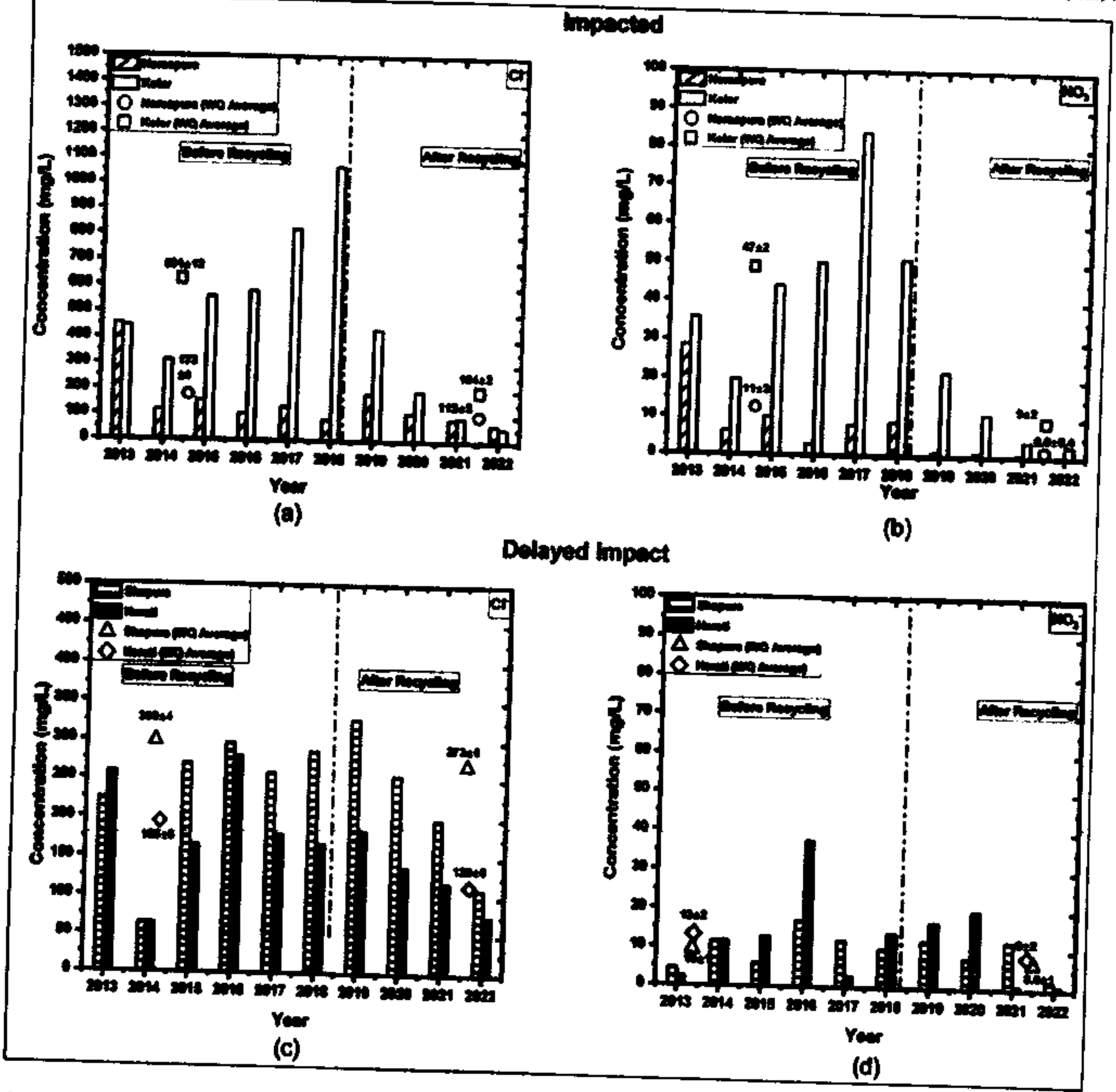

Fig. 9. Impact on groundwater quality (Anions)
Source: KGWA and CGWB
Note: Before recycling period is 2013–2017 whereas after recycling period is 2018–2022.

Pedrero et al. (2010) supports the results of the presented study and reported positive impact on GW, agricultural sector, and socio-economic conditions in water-scarce regions through managed aquifer recharge (MAR).

4. Conclusions

In conclusion, this study highlights the success of large-scale recycling of secondary treated wastewater in addressing freshwater scarcity in water-stressed regions, particularly the semi-arid Kolar district. The large scale recycling of secondary treated wastewater effectively rejuvenated existing surface tanks and recharged groundwater in neighbouring villages of Bangalore city. The AMBHAS_1D model was utilized to quantify the groundwater recharge rates in hard rock aquifers with fractured gneiss, granites, schists, and highly fractured weathered rocks, and the results demonstrated recharge rates up to 3 mm/day, which is 10 times the otherwise recharge rates. This study also quantifies the positive impacts of this recycling effort on groundwater levels and quality. Due to additional recharge coming from the recycling of secondary treated wastewater, the groundwater levels increased by 58 to 73 %. Also, due to infiltration through the tank soil and strata, the groundwater hardness improved by 50–70 %. Furthermore, the land use and land cover studies confirmed a fivefold increase in water bodies, resulting in a significant reduction in background and rangeland, increased agricultural activities, increased milk production and increased fish production.

These findings provide valuable insights for stakeholders to accelerate plans for reusing treated wastewater for indirect groundwater recharge and conserving freshwater. Large-scale water recycling schemes, such as the K&C valley project, can be replicated in towns and cities facing drought

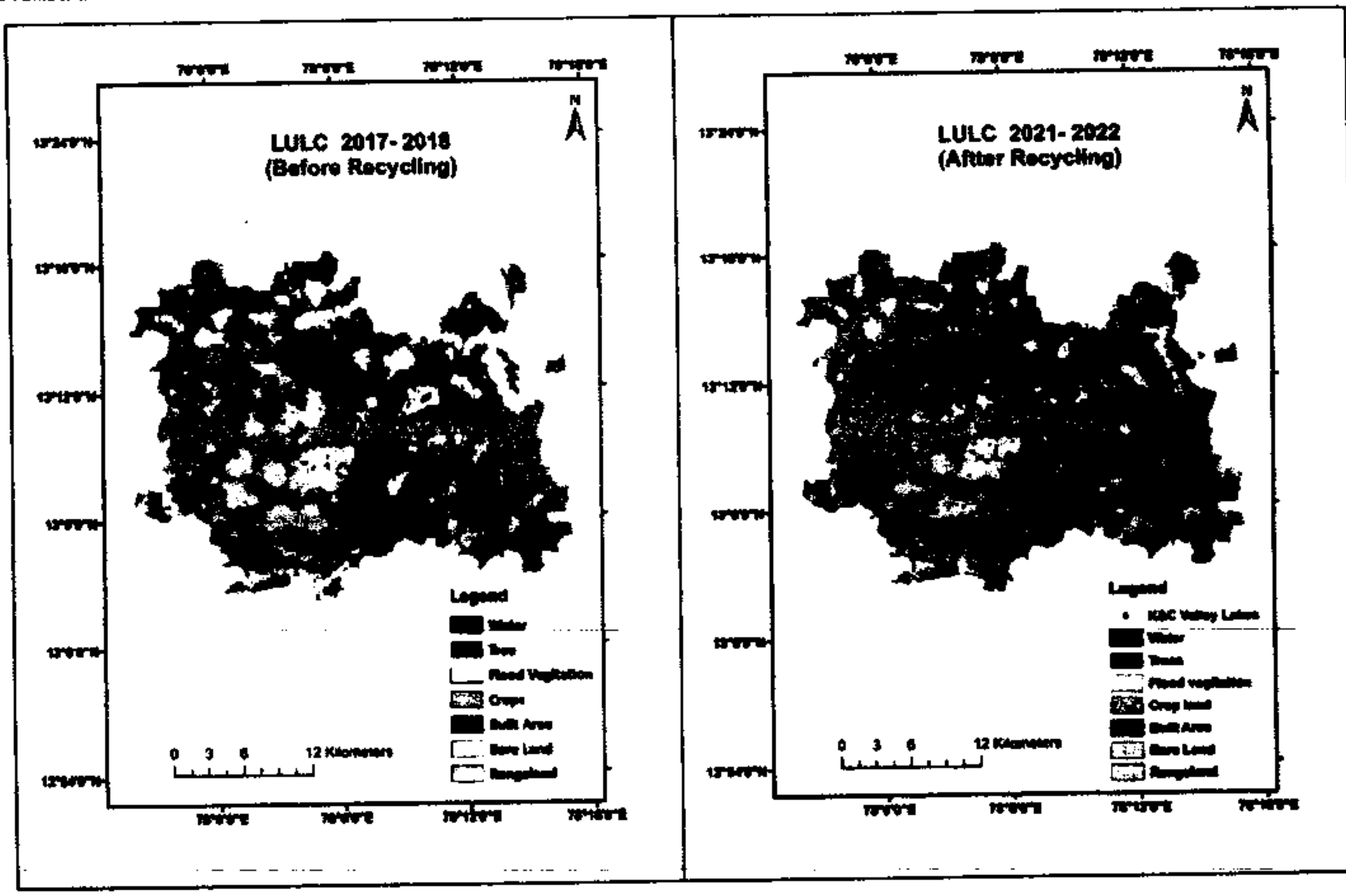

Fig. 10. Impact on LULC (2017–2018 to 2021–2022)
Source: ESRI (2017 to 2022).

situations, providing long-term water security. However, it is crucial to monitor groundwater quality regularly and investigate the long-term impacts of using secondary treated wastewater for indirect groundwater recharge. By doing so, we can continue to address freshwater scarcity sustainably while supporting agricultural and economic growth in water-stressed regions.

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CRediT authorship contribution statement

Kavita Verma – Corresponding Author, study design, data collection, analysis, and drafting of the manuscript.

Manjari Manisha –Study on Socio-economic aspects, data collection, analysis, and drafting of the manuscript.

Santrupt RM- Data collection and analysis, and plotting graphs.

Anirudha TP- Data collection and analysis, and plotting graphs.

Shubham Goswami- Groundwater Modelling and Analysis.

M. Sekhar- Conception, Groundwater Modelling, and review of the article.

Ramesh N- Data collection from different organizations for the socio-economic study.

Mohan Kumar MS- Conception, designing of the study, and review of the article.

Chanakya HN- Conception, designing of the study, and review of the article.

Lakshminarayana Rao- Conception, designing of the study, and review of the article.

Note: Santrupt RM and Anirudha TP have an equal contribution.

Data availability

Data will be made available on request.

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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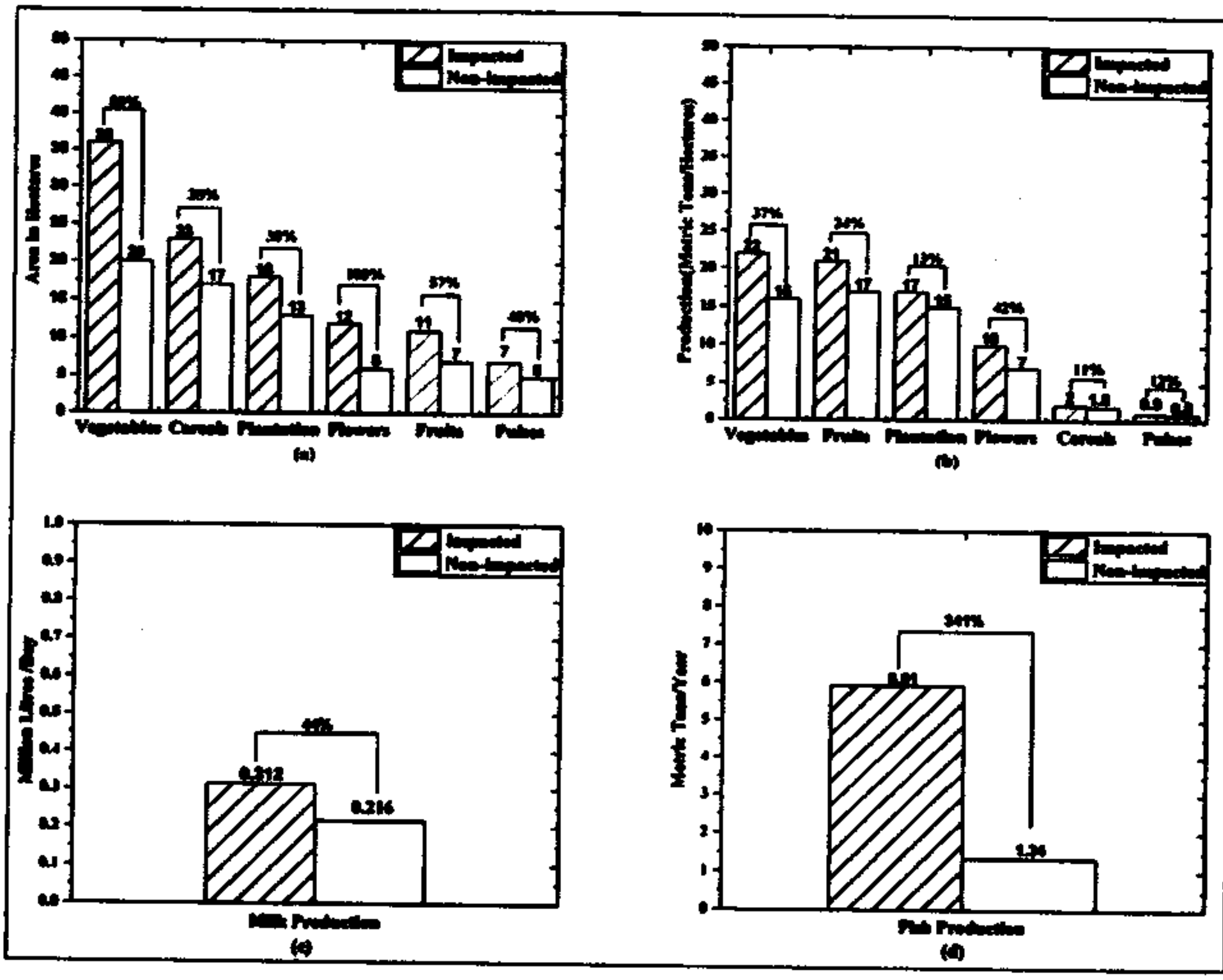

Fig. 11. (a) and (b) Impact on crop productivity, (c) milk and (d) fish production for 2021–2022
Source: Department of Agriculture & Horticulture Kolar, milk production data (2021–2022) from Kolar-Chikkaballapur district co-operative milk producer's societies union ltd. Kolar, and fishery data (2021–2022) Department of Fishery Sciences, 2021, Kolar.
Note: Plantations represent cultivation of- cashew, silver oak, eucalyptus, coconut, areca nut, tamarind, and mulberry; Vegetables- tomato, potato, beans, cabbage, green chili, capsicum, carrot, etc.; Fruits- mango, banana, sapota, guava, grapes, watermelon, pomegranates, papaya, etc.; Cereals- ragi, paddy, maize, jowar, minor millets, etc.; Flower- marigold, chrysanthemum, jasmine, rose, crossandra, etc.; Pulses-red gram, field bean, toor, cowpea, horse gram, green gram, etc. Oil seed – ground nut, sunflower.

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References

Abu, A., Carrey, R., Valhondo, C., Domenech, C., Soler, A., Martinez-Landa, L., Diaz-Cruz, S., Carrera, J., Otero, N., 2022. Pathways and efficiency of nitrogen attenuation in wastewater effluent through soil aquifer treatment. J. Environ. Manag. 321, 115927.

Alam, S., Borthakur, A., Ravi, S., Gebremichael, M., Mohanty, S.K., 2021. Managed aquifer recharge implementation criteria to achieve water sustainability. Sci. Total Environ. 768, 144992.

Alidina, M., Li, D., Ouf, M., Drewes, J.E., 2014. Role of primary substrate composition and concentration on attenuation of trace organic chemicals in managed aquifer recharge systems. J. Environ. Manag. 144, 58–66.

Amin, H.M., Gad, A., El-Rawy, Mustafa, Abdelghany, U.A., Sadeek, R.A., 2022. Improvement of partially treated wastewater quality by soil aquifer treatment in upper Egypt. Journal of Engineering Science and Technology 17 (1), 0689–0712.

Anuraga, T.S., Ruiz, L., Kumar, M.M., Sekhar, M., Leijnse, A., 2006. Estimating groundwater recharge using land use and soil data: a case study in South India. Agric. Water Manag. 84 (1–2), 65–76.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Asano, T., Cotruvo, J.A., 2004. Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. Water Res. 38 (8), 1941–1951.

Awual, M.R., 2016. Assessing of lead (III) capturing from contaminated wastewater using ligand doped conjugate adsorbent. Chem. Eng. J. 289, 65–73.

Awual, M.R., 2019. A facile composite material for enhanced cadmium (II) ion capturing from wastewater. J. Environ. Chem. Eng. 7 (5), 103378.

Awual, M.R., Hasan, M.M., 2015. Fine-tuning mesoporous adsorbent for simultaneous ultra-trace palladium (II) detection, separation and recovery. J. Ind. Eng. Chem. 21, 507–515.

Awual, M.R., Hasan, M.M., Islam, A., Asiri, A.M., Rahman, M.M., 2020. Optimization of an innovative composited material for effective monitoring and removal of cobalt (II) from wastewater. J. Mol. Liq. 298, 112035.

Barry, K.E., Vanderzalm, J.L., Miotlinski, K., Dillon, P.J., 2017. Assessing the impact of recycled water quality and clogging on infiltration rates at a pioneering soil aquifer treatment (SAT) site in Alice Springs, Northern Territory (NT), Australia. Water 9 (3), 179.

Bouwer, H., 1991. Groundwater recharge with sewage effluent. Water Sci. Technol. 23 (10–12), 2099–2108.

Bekele, E., Toze, S., Patterson, B., Higginson, S., 2011. Managed aquifer recharge of treated wastewater: water quality changes resulting from infiltration through the vadose zone. Water Res. 45 (17), 5764–5772.

Bergstrom, C., McKeel, C., Patel, S., 2007. Effects of pH on Algal Abundance: A Model of Bay Harbor, Michigan.

BIS (Bureau of Indian Standards) 10500, 2012. Specification for Drinking Water. Indian Standards Institution, New Delhi, pp. 1–5.

Census India, 2011. Kolar District Population, Karnataka. . https://www.censusindia2011.com/karnataka/kolar-population.html.

CGWB, 2012. Groundwater Information Booklet Kolar District, Karnataka. Ministry of water resource, Central Groundwater Board Bangalore, India.

CGWB, 2020. National complication on dynamic groundwater resources of India. . https://cgwb.gov.in/documents/2021-08-02-GWRA_India_2020.pdf.

CGWB (Kolar district profile), 2009. Ground Water Information Booklet Available at: Microsoft Word KOLAR_BROCHURE.doc (cgwb.gov.in).

Chen, G., Meng, T., Wu, W., Si, B., Li, M., Liu, B., Wu, S., Feng, H., Siddique, K.H., 2023. Evaluating potential groundwater recharge in the unsteady state for deep-rooted afforestation in deep loess deposits. Sci. Total Environ. 858, 159837.

Collins, S.L., Loveless, S.E., Muddu, S., Buvaneshwari, S., Palamakumbura, R.N., Krabbendam, M., Lapworth, D.J., Jackson, C.R., Gooddy, D.C., Nara, S.N.V., Chattopadhyay, S., 2020. Groundwater connectivity of a sheared gneiss aquifer in the Cauvery River basin, India. Hydrogeol. J. 28, 1371–1388.
Crites, R.W., Middlebrooks, E.J., Bastian, R.K., 2014. Natural wastewater treatment systems. CRC press.
Dangar, S., Asoka, A., Mishra, V., 2021. Causes and implications of groundwater depletion in India: a review. J. Hydrol. 596, 126103.
Department of Fishery Sciences, Kolar, 2021. . Available at http://www.fisheries-kolar.com/.
DEIAA, 2019. http://environmentclearance.nic.in/writereaddata/FormB/TOR/ConceptualPlan/30_May_2019_1137552231XT0QJDSODistrictSurveyReportKolar.pdf.
Dihan, M.R., Nayeem, S.A., Roy, H., Islam, M.S., Islam, A., Alsukaibi, A.K., Awual, M.R., 2023. Healthcare waste in Bangladesh: current status, the impact of Covid-19 and sustainable management with life cycle and circular economy framework. Sci. Total Environ. 162083.
Dillon, P., Arshad, M., 2016. Managed aquifer recharge in integrated water resource management. Integrated Groundwater Management. Springer, Cham, pp. 435–452.
El Arabi, N.E., Dawoud, M.A., 2012. Groundwater aquifer recharge with treated wastewater in Egypt: technical, environmental, economic and regulatory considerations. Desalin. Water Treat. 47 (1–3), 266–278.
Engberg-Pedersen, L., 2011. Coping with poverty and institutionalised practices: Tank-irrigated cultivation in Kolar District, Karnataka (No. 2011: 09). Available atDIIS Working Paper.
Eslamian, S., Hedayat, E., Esfahani, S.T., Ostad-Ali-Askari, K., Singh, V.P., Dalezios, N.R., Matouq, M., 2018. The reuse of treated wastewater via groundwater recharge for the development of sustainable water resources. International Journal of Rural Development, Environment and Health Research 2, 62–67. https://doi.org/10.22161/ijreh.2.5.4 ISSN 2456-8678.
ESRI (Environmental systems research institute Land cover), 2017-2022. Land Use Land Cover. . https://www.esri.com/en-us/home.
Ganot, Y., Holtzman, R., Weisbrod, N., Russak, A., Katz, Y., Kurtzman, D., 2018. Geochemical processes during managed aquifer recharge with desalinated seawater. Water Resour. Res. 54 (2), 978–994.
Garg, K.K., Anantha, K.H., Nune, R., Akuraju, V.R., Singh, P., Gumma, M.K., Dixit, S., Ragab, R., 2020. Impact of land use changes and management practices on groundwater resources in Kolar district, southern India. J. Hydrol.: Reg. Stud. 31, 100732.
Garg, S., Motagh, M., Indu, J., Karanam, V., 2022. Tracking hidden crisis in India's capital from space: implications of unsustainable groundwater use. Sci. Rep. 12 (1), 1–17.
GoK (Government of Karnataka), 2016. District irrigation plan – Kolar district. Available atPradhana Mantri Krishi Sinchayee Yojane (PMKSY). https://pmksy.gov.in/AboutPMKSY.aspx.
Goswami, S., Sekhar, M., 2022. Estimation of specific yield of hard-rock aquifers in Upper Cauvery River basin region in India by application of AMBHAS-1D groundwater model (No. EGU22-9975). Copernicus Meetings.
Goswami, S., Sekhar, M., 2022b. Investigation and evidence of high episodic groundwater recharge events in tropical hard-rock aquifers of southern India. Front. Water https://doi.org/10.3389/frwa.2022.960669.
Grinshpan, M., Furman, A., Dahlke, H.E., Raveh, E., Weisbrod, N., 2021. From managed aquifer recharge to soil aquifer treatment on agricultural soils: concepts and challenges. Agric. Water Manag. 255, 106991.
Hasan, M.M., Shenashen, M.A., Hasan, M.N., Znad, H., Salman, M.S., Awual, M.R., 2021. Natural biodegradable polymeric bioadsorbents for efficient cationic dye encapsulation from wastewater. J. Mol. Liq. 323, 114587.
Hasan, M.M., Kubra, K.T., Hasan, M.N., Awual, M.E., Salman, M.S., Sheikh, M.C., Rehan, A.I., Rasee, A.I., Waliullah, R.M., Islam, M.S., Khandaker, S., 2023. Sustainable ligand-modified based composite material for the selective and effective cadmium (II) capturing from wastewater. J. Mol. Liq. 371, 121125.
Hussain, J., Husain, I., Arif, M., Gupta, N., 2017. Studies on heavy metal contamination in Godavari River basin. Appl Water Sci 7 (8), 4539–4548.
Icekson-Tal, N., Avraham, O., Sack, J., Cikurel, H., 2003. Water reuse in Israel-the dan region project: evaluation of water quality and reliability of plant's operation. Water Sci. Technol. Water Supply 3 (4), 231–237.
Islam, A., Teo, S.H., Awual, M.R., Taufiq-Yap, Y.H., 2020. Assessment of clean H2 energy production from water using novel silicon photocatalyst. J. Clean. Prod. 244, 118805.
Islam, A., Teo, S.H., Taufiq-Yap, Y.H., Ng, C.H., Vo, D.V.N., Ibrahim, M.L., Hasan, M.M., Khan, M.A.R., Nur, A.S., Awual, M.R., 2021. Step towards the sustainable toxic dyes removal and recycling from aqueous solution-a comprehensive review. Resour. Conserv. Recycl. 175, 105849.
Jovanovic, N., Bugan, R.D., Tredoux, G., Israel, S., Bishop, R., Marinus, V., 2017. Hydrogeological modelling of the Atlantis aquifer for management support to the Atlantis water supply scheme. Water SA 43 (1), 122–138.
KSNDMC, 2009. http://www.ksndmc.org/.
Karnataka State Natural Disaster Monitoring Centre (2020), https://www.ksndmc.org/Default.aspx.
Kumar, S., 2016. Soil moisture modelling, retrieval from microwave remote sensing and assimilation in a tropical watershed Doctoral dissertation.
Leavitt, P.R., Findlay, D.L., Hall, R.I., Smol, J.P., 1999. Algal responses to dissolved organic carbon loss and pH decline during whole-lake acidification: evidence from paleolimnology. Limnol. Oceanogr. 44 (3, part 2), 757–773.
Manisha, M., Verma, K., Ramesh, N., Anirudha, T.P., Santrupt, R.M., Das, R., Kumar, M.M., Chanakya, H.N., Rao, L., 2023. Socio-economic impact assessment of large-scale recycling of treated municipal wastewater for indirect groundwater recharge. Sci. Total Environ. 859, 160207.
Marechal, J.C., Dewandel, B., Ahmed, S., Galeazzi, L., Zaidi, F.K., 2006. Combined estimation of specific yield and natural recharge in a semi-arid groundwater basin with irrigated agriculture. J. Hydrol. 329 (1–2), 281–293.
Maurya, A., Singh, M.K., Kumar, S., 2020. Biofiltration technique for removal of waterborne pathogens. Waterborne Pathogens. Butterworth-Heinemann, pp. 123–141.
Mazrouaa, A.M., Mansour, N.A., Abed, M.Y., Youssif, M.A., Shenashen, M.A., Awual, M.R., 2019. Nano-composite multi-wall carbon nanotubes using poly (p-phenylene terephthalamide) for enhanced electric conductivity. J. Environ. Chem. Eng. 7 (2), 103002.
McCance, W., Jones, O.A.H., Cendon, D.I., Edwards, M., Surapaneni, A., Chadalavada, S., Wang, S., Currell, M., 2020. Combining environmental isotopes with contaminants of emerging concern (CECs) to characterise wastewater derived impacts on groundwater quality. Water Res. 182, 116036.
Mishra, P., Naik, S., Babu, P.V., Pradhan, U., Begum, M., Kaviarasan, T., Vashi, A., Bandyopadhyay, D., Ezhilarasan, P., Panda, U.S., Murthy, M.R., 2022. Algal bloom, hypoxia, and mass fish kill events in the backwaters of Puducherry, southeast coast of India. Oceanologia 64 (2), 396–403.
Modrzynski, J.J., Aamand, J., Wittorf, L., Badawi, N., Hubalek, V., Canelles, A., Haltin, S., Albers, C.N., 2021. Combined removal of organic micropollutants and ammonium in reactive barriers developed for managed aquifer recharge. Water Res. 190, 116669.
Nandan, M.J., Surinaidu, L., Kumar, D., 2021. Sustainable irrigation and economic development through community participated managed aquifer recharge in water scarce regions of Telangana state — a case study. J. Geol. Soc. India 97, 1294–1299.
Nandanwar, M.A.A., Raut, M.A.Y., Qureshi, M.A.S., Bande, M.C.M., Dhawase, M.J.M., Khobragade, M.M.M., 2020. A Review Paper on Groundwater Recharge by Utilizing Waste Water from Residential Area.
NEERI, National Environmental Engineering Research Institute, 2015. Project Completed, Page - 4 - Water Technology and Management Division/The Official Website of CSIR-National Environmental Engineering Research Institute, Government of India.
NGT, National Green Tribunal, 2019. Available at https://greentribunal.gov.in/sites/default/files/all_documents/4th-report-alongwith-annexures_compressed.pdf.
Ofori, S., Puskacova, A., Ruzickova, I., Wanner, J., 2021. Treated wastewater reuse for irrigation: pros and cons. Sci. Total Environ. 760, 144026.
Okello, C., Tomasello, B., Greggio, N., Wambiji, N., Antonellini, M., 2015. Impact of population growth and climate change on the freshwater resources of Lamu IslandKenya. Water 7 (3), 1264–1290.
Packialakshmi, S., Balaji, S., Kumaresan, T., 2015. Inducing recharge of groundwater by treated waste water—a pilot study in southern Chennai metropolitan area. Indian J. Sci. Technol. 8 (11).
Park, E., Parker, J.C., 2008. A simple model for water table fluctuations in response to precipitation. J. Hydrol. 356 (3–4), 344–349.
Patil, A.V., Mankar, T.S., Motegaonkar, S.S., 2017. Wastewater Renovation using Soil Aquifer Treatment (SAT) System: Case Study of Latur District (Marathwada).
Pedrero, F., Kalavrouziotis, I., Alarcón, J.J., Koukoulakis, P., Asano, T., 2010. Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. Agric. Water Manag. 97 (9), 1233–1241.
Rahman, M.A., Rusteberg, B., Gogu, R.C., Ferreira, J.L., Sauter, M., 2012. A new spatial multi-criteria decision support tool for site selection for implementation of managed aquifer recharge. J. Environ. Manag. 99, 61–75.
Ramaiah, S.N., Reddy, R., Reddy, V.J., 2017. Over-exploitation of groundwater, and its impact on phreatic aquifer system, surface water bodies and rural water supply schemes in malur taluk, Kolar District, Karnataka-a case study. Nat. Environ. Pollut. Technol. 16 (2), 599.
Rao, H., Rao, L., Chanakya, H.N., 2021. Fate of heavy metals in sewage and polluted water bodies. Curr. Sci. 121 (1), 109.
Rasel, H.M., Al Mamun, M.A., Hasnat, A., Alam, S., Hossain, I., Mondal, R.K., Good, R.Z., Alsukaibi, A.K., Awual, M.R., 2023. Sustainable futures in agricultural heritage: geospatial exploration and predicting groundwater-level variations in Barind tract of Bangladesh. Sci. Total Environ. 865, 161297.
Saleem, M., Hussain, A., Mahmood, G., 2016. Analysis of groundwater quality using water quality index: a case study of Greater Noida (Region), Uttar Pradesh (UP)India. Cogent Engineering 3 (1), 1237927.
Sekhar, M., Shindekar, M., Tomer, S.K., Goswami, P., 2013. Modeling the vulnerability of an urban groundwater system due to the combined impacts of climate change and management scenarios. Earth Interact. 17 (10), 1–25.
Sharma, S.K., Kennedy, M.D., 2017. Soil aquifer treatment for wastewater treatment and reuse. Int. Biodeterior. Biodegrad. 119, 671–677.
Shawaqfah, M., Almomani, F., Al-Rousan, T., 2021. Potential use of treated wastewater as groundwater recharge using gis techniques and modeling tools in dhuleil-halabat well-field/Jordan. Water 13 (11), 1581.
Singh, C., 2020. Of borewells and bicycles1: the gendered nature of water access in Karnataka, South India and its implications for local vulnerability. Engendering Climate Change. Routledge India, pp. 58–84.
Siva Prasad, Y., Venkateswara Rao, B., 2018. Groundwater recharge estimation studies in a khondalitic terrain of India. Appl. Water Sci. 8 (4), 1–9.
Sivapullaiah, P.V., Kantha, H.L., Kiran, K.M., 2003. Geotechnical properties of stabilised Indian red earth. Geotech. Geol. Eng. 21 (4), 399–413.
Subash, Y., Sekhar, M., Tomer, S.K., Sharma, A.K., 2017. A Framework for Assessment of Climate Change Impacts on Groundwater System Formations. Sustainable water Resources Management, pp. 375–397.
Sunyer-Caldú, A., Benedetti, B., Valhondo, C., Martinez-Landa, L., Carrera, J., Di Carro, M., Diaz-Cruz, M.S., E., 2023. Using integrative samplers to estimate the removal of pharmaceuticals and personal care products in a WWTP and by soil aquifer treatment enhanced with a reactive barrier. Sci. Total Environ. 867, 161466.
Teo, S.H., Ng, C.H., Islam, A., Abdulkareem-Alsultan, G., Joseph, C.G., Janaun, J., Taufiq-Yap, Y.H., Khandaker, S., Islam, G.J., Znad, H., Awual, M.R., 2022. Sustainable toxic dyes removal with advanced materials for clean water production: a comprehensive review. J. Clean. Prod. 332, 130039.

Van Houtte, E., Verbauwhede, J., 2012. Sustainable groundwater management using reclaimed water: the Torreele/St-André case in FlandersBelgium. Journal of Water Supply: Research and Technology—AQUA 61 (8), 473–483.

Veeranna, J., Jeet, P., 2020. Groundwater recharges technology for water resource management: A case study. Groundwater Management and Resources. IntechOpen.

Wakode, H.B., Baier, K., Jha, R., Azzam, R., 2018. Impact of urbanization on groundwater recharge and urban water balance for the city of Hyderabad, India. Int. Soil Water Conserv. Res. 6 (1), 51–62.

Wei, L., Li, S., Noguera, D.R., Qin, K., Jiang, J., Zhao, Q., Kong, X., Cui, F., 2015. Dissolved organic matter removal during coal slag additive soil aquifer treatment for secondary effluent recharging: contribution of aerobic biodegradation. J. Environ. Manag. 156, 158–166.

Wilson, L.G., Quanrud, D., Arnold, R., Amy, G., Gordon, H., Conroy, A.D., 1995. Field and laboratory observations on the fate of organics in sewage effluent during soil aquifer treatment. International Symposium on Artificial Recharge of Ground Water - Proceedings. ASCE, Orlando, FL, USA.

Yaqub, M., Ngoc, N.M., Park, S., Lee, W., 2022. Predictive modeling of pharmaceutical product removal by a managed aquifer recharge system: comparison and optimization of models using ensemble learners. J. Environ. Manag. 324, 116345.

Zaibel, I., Zilberg, D., 2021. Treated municipal wastewater as a water source for sustainable aquaculture: a review. Rev. Aquac. 14 (4).

Zaibel, I., Appelbaum, Y., Arnon, S., Britzi, M., Schwartsburd, F., Snyder, S., Zilberg, D., 2019. The effect of tertiary treated wastewater on fish growth and health: laboratory-scale experiment with poecilia reticulate (guppy). PloS one 14 (6), e0217927.

Zhang, H., Huo, M., Pan, W., Zhu, S., Lu, Y., Xiong, H., Geng, W., Dong, L., 2018. Water quality variation and hydrogeochemical evolution during artificial groundwater recharge with reclaimed water: laboratory experimental and numerical simulation study. Arab. J. Geosci. 11 (13), 1–16.

Water Quality Analysis

Report

भारतीय विज्ञान संस्थान

Submitted By:

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8th August 2025

Water Quality Analysis

IISc Bengaluru under the K&C Valley project has been periodically monitoring the water quality of STP effluent. The water quality of the analysed STP effluent between January 2025 to June 2025 is presented in Table 1 and Table 2:

Table 1: Water quality of STP final treated effluent

Sl. No.	Parameters	Unit	Hon'ble NGT discharge standards (NGT, 2019)	STP Outlet/DC Point					
				25-Jan	25-Feb	25-Mar	25-Apr	25-May	25-Jun
1	pH	-	6.5-9.0	7.2	7	7	7.2	7.2	7.4
2	BOD5 (@20 °C)	mg/L	10	3.7 ± 0	4.5 ± 0	6.4 ± 0	8.3 ± 0	15.6 ± 0	2 ± 0
3	COD	mg/L	50	24 ± 2.8	42 ± 5.7	37 ± 5.5	39 ± 1.4	40 ± 2.7	NA
4	TSS	mg/L	10	8 ± 1	9 ±1	5 ± 1.5	8 ±1	9 ± 1	10 ± 1
5	NH_4 -N	mg/L	5	1.14 ± 0.07	0.39 ± 0.03	0.04 ± 0.02	1.71 ± 0.15	4.9 ± 0.08	8.1 ± 0.09
6	TN	mg/L	10	8 ± 2	9 ± 1	6 ± 3	10 ± 2	9 ± 1	NA
7	PO_4- P	mg/L	1	1.3 ± 0	1.3 ± 0	1.3 ± 0.1	0.6 ± 0	0.7 ± 0	0.6 ± 0
8	Faecal Coliform	MPN/100 mL	< 230 allowable	>230	>230	>230	>230	>230	>230

NA = Not available

Remarks

- The water quality at the DC points meets the Honorable NGT standards for all parameters except for E-coli.

Table 2: Water quality (heavy metals) of STP final treated effluent

Sl.No.	**Metals, metalloids, and heavy metals**	**IS 10500 (mg/L)** (BIS 10500, 2012)	**Secondary treated wastewater (mg/L)**
1	Iron (Fe)	3	0.36 ± 0.02
2	Manganese (Mn)	2	0.02 ± 0
3	Zinc (Zn)	5	BDL ± 0
4	Cadmium (Cd)	2	BDL ± 0
5	Lead (Pb)	0.1	BDL ± 0
6	Arsenic (As)	0.2	0.001 ± 0
7	Chromium (Cr^{+5})	0.1	<0.1 ± 0
8	Nickel (Ni)	3	0.028 ± 0
9	Copper (Cu)	3	0.00 ± 0
10	Aluminium (Al)	0.2	BDL ± 0
11	Barium (Ba)	0.7	0.045 ± 0
12	Boron (B)	0.5	0.021 ± 0
13	Selenium (Se)	0.01	BDL ± 0
14	Silver (Ag)	0.1	BDL ± 0
15	Mercury (Hg)	0.001	BDL ± 0
16	Molybdenum (Mo)	0.07	0.001 ± 0

Note: *BDL is below the detection limit of* $1x10^{-6}$ *mg/L*

Remarks

- The heavy metals are not detected in the STP final treated water reaching at the DC point of Kolar. In fact, the heavy metal levels are meeting drinking water standards IS10500:2012

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29th of September 2025

Assessing the Impact of Indirect Groundwater Recharge through Recycled Water on Public health in KC Valley Project

To
The Executive Engineer
Kolar Division
MI Department
Bangalore
Karnataka

Dear Sir,

Further to your request, I am sharing with you the findings on the human health survey data we obtained from Directorate of Health and Family Welfare Service, Kolar to understand if any changes in disease patterns after implementation of project

Please do let me know if you have any other questions

Best Regards

Dr. Lakshminarayana Rao
CST, IISc

Assessing the Impact of Indirect Groundwater Recharge through Recycled Water on Public health in KC Valley Project

1. **Objective:**

This study aims to quantify the impacts of water recycling project for indirect GW recharge on public health.

2. **Methodology**

To obtain the study's objectives quantitative data were collected and comprehensively analyzed. To assess the prevalence of diseases in the Kolar district over the past nine years (2015-2023), quantitative data was obtained from the Directorate of Health and Family Welfare Service, Kolar to understand if any changes in disease patterns after implementation of project, particularly waterborne diseases.

3. **Result**

3.1 Analysis of public health data received from health departments, Kolar

Data received from the Directorate of Health and Family Welfare Service, Kolar, Government of Karnataka, indicates a comprehensive overview of the prevalence of waterborne, and water-related, diseases in the Kolar Taluka which is one of the impacted areas. The ten identified diseases include diarrhea-gastroenteritis, typhoid, bacillary dysentery, viral hepatitis, leptospirosis, Japanese encephalitis, malaria, dengue, chikungunya, and skin diseases.

Summary of the findings

- Total prevalence of diseases reduced by 67% from 11012 cases during pre-recycling period to 3627 during post-recycling period. This is attributed to increased hygiene practices due higher availability of the water
- Typhoid fever cases decreased by 85% from 673 to 100.
- Bacillary dysentery cases decreased by 70% from 588 to 174.
- Diarrhea-gastroenteritis cases decreased by 67% from 9312 to 2990.
- Viral hepatitis-A cases reduced by 53% from 83 to 39.
- Leptospirosis decreased by 53% from 63 to 29.
- Skin diseases includes rashes, eczema, blisters, redness, itching reduced by 10% from 150 to 135.
- Malaria cases decreased by 57% from 7 to 2.
- Dengue did not indicate a distinct increase or decrease pattern, during both period average cases was 70.

4. Conclusions

Based on data collected in this study from the Directorate of Health and Family Welfare Services, Government of Karnataka, the analysis indicates that the reuse of secondary treated wastewater for indirect groundwater recharge through the Soil Aquifer Treatment technique does not adversely affect public health. On the contrary, improvements in hygiene and WASH scores were observed, as evidenced by the decline in waterborne diseases. This positive outcome can be attributed to better water availability, improved sanitation and hygiene practices, and enhanced nutritional intake. In the context of growing water scarcity, particularly in semi-arid regions, decision-makers should prioritize and support projects that strengthen water security through sustainable water reuse. Overall, this study recommends that policymakers actively promote the reuse of treated wastewater for indirect groundwater recharge.

Groundwater Quality and Water-Level Response to Recharge in the KC Valley Project

Report for

January 2026

Submitted By:

CST, IISc Bengaluru

29th January 2026

Groundwater Quality and Water-Level Response to Recharge in the KC Valley Project

Groundwater recharge assessment by the Centre for Sustainable Technologies, Indian Institute of Science (IISc) indicates (Fig. 1) that groundwater-level time series exhibit a sustained rise beyond precipitation variability, providing clear evidence of recharge-driven aquifer response in the impacted Kolar region. A significant post-recharge shift in groundwater quality is observed in impacted locations. Comparative evaluation of water quality during the pre-recharge (2014–2018) and post-recharge (2019–2025) periods shows consistent reduction trends across monitored hydrochemical indicators in the impacted region (Fig. 2).

Annexure–I: Groundwater level vs precipitation (2014–2025)

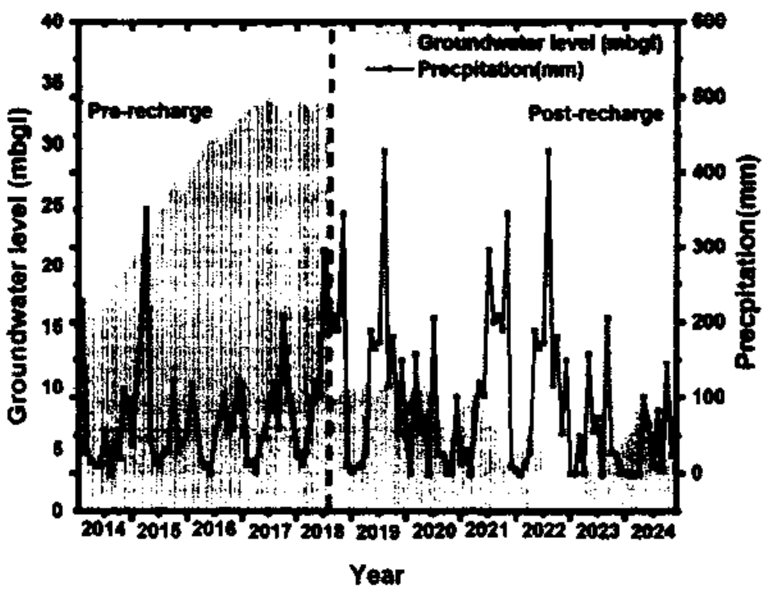

Fig. 1: Groundwater level response in Impacted region

Annexure–II: Groundwater quality comparison (Pre- vs Post-recharge)

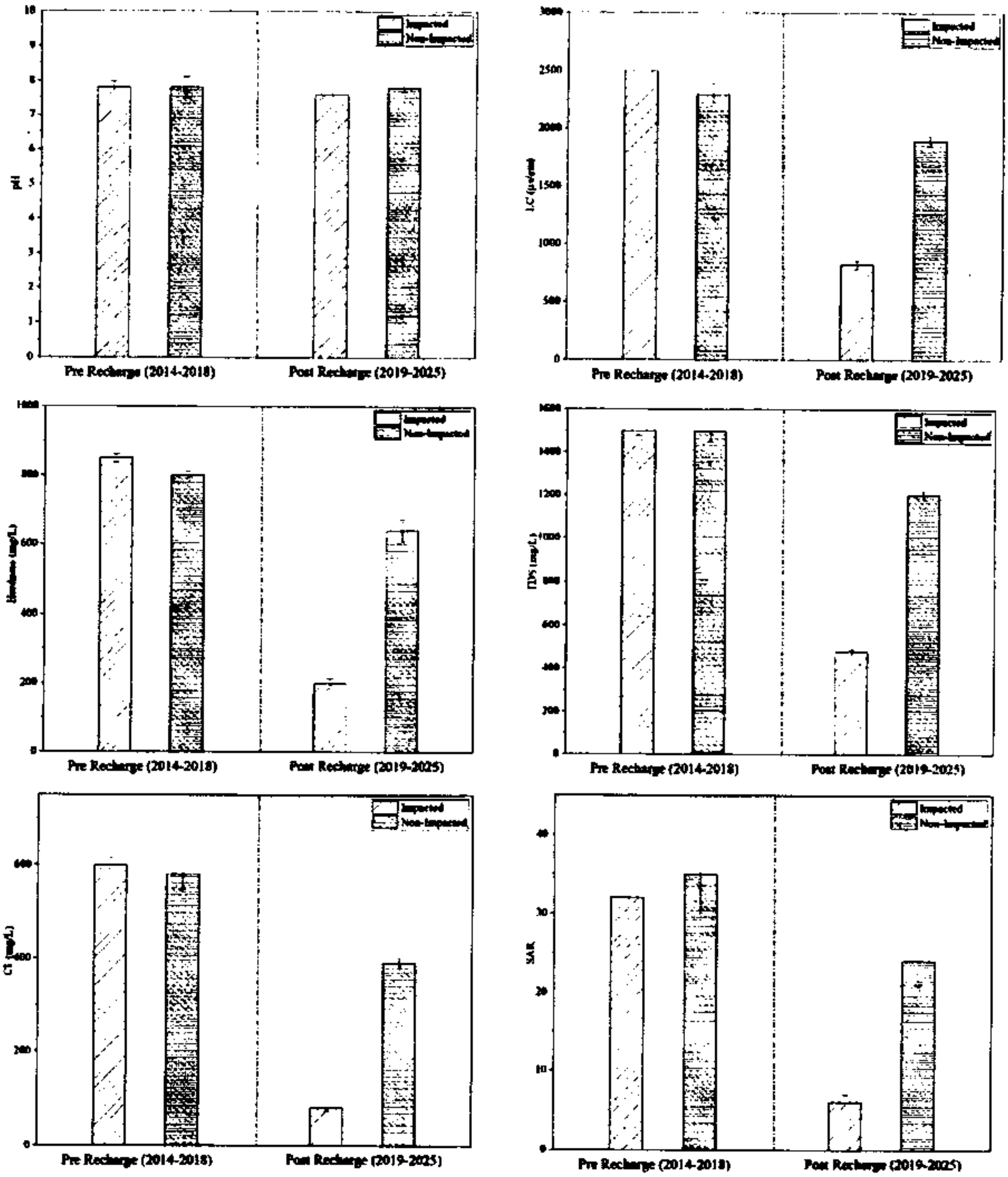

Fig. 2: Comparison of groundwater quality indicators in impacted and non-impacted locations.

Summary of Findings

- Groundwater-level analysis indicates a marked and sustained rise in water levels in impacted locations following implementation of the KC Valley project, irrespective of precipitation variability, confirming recharge-driven aquifer response (Fig. 1).
- During the pre-recharge period (2014–2018), declining groundwater levels corresponded with elevated concentrations of total dissolved solids (TDS), hardness, chloride (Cl^-), sodium adsorption ratio (SAR), and electrical conductivity (EC), indicating degraded groundwater quality conditions.
- Post-recharge observations (2019–2025) show a consistent reduction in TDS, hardness, Cl^-, SAR, and EC in impacted locations, as shown in Fig. 2, reflecting the influence of dilution and recharge processes.
- Comparative analysis further indicates that impacted locations exhibit better groundwater quality than non-impacted locations during the post-recharge period, particularly with respect to salinity- and sodicity-related indicators.
- The combined improvement in groundwater levels and reduction in key hydrochemical parameters demonstrates the positive impact of the KC Valley recharge intervention on aquifer quantity and quality in the impacted Kolar region.

bw2019-6

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2nd of March 2026

K&C Valley Treated Wastewater Reuse Project – Level of Water Treatment

The water pumped from borewells in Kolar district under the K&C Valley project is an ultra-high level treated water that is subject to 5 levels of treatment, one level in advanced sewage treatment plants (STP) and another four levels following nature-based solutions (NBS). These five stages culminate in a form of soil aquifer treatment (SAT) method which is a part of the managed aquifer recharge (MAR)—where treated wastewater is filtered through several natural soil layers, effectively removing contaminants and also improving groundwater quality by diluting the endemic fluoride content as well as the high salts within. Needless to state, the resulting groundwater is at a better quality and is bereft of the high salt and fluoride content.

To meet National Green Tribunal (NGT, 2019) discharge standards, conventional STPs (originally built in 1979) were upgraded with process modification design details provided by IISc (in 2018) for incorporating Biological Nutrient Removal (BNR) systems, disc filtration, and partial chlorination. This resembles tertiary-treated water, holding adequate micro-macronutrients, supports aquatic life in the receiving tanks/lakes. This in turn provides the basis for micro and macro living forms in the lake water that is needed to keep the water healthy and in turn promotes fisheries, contributing to local biodiversity revival.

Considering the above, utilizing severe treatment methods such as RO, etc. that strips the water of these nutrients will only create dead lakes bereft of life in place of the "Living Lakes of Kolar" that retains the self-cleaning capability required to overcome human, animal and bird intrusions along the way. It is thus predicted that tertiary or RO treated water will only negatively impact aquatic flora and fauna resulting in loss of biodiversity.

The K&C Valley Project, launched in 2018 by the Government of Karnataka, aims to address water scarcity in the semi-arid Kolar and Chikkaballapur districts by channelling secondary treated wastewater (STW) from Bengaluru's sewage treatment plants (STPs) to 137 village tanks ("Kere"). The initiative covers 24,000 hectares of agricultural land and benefits nearly 2 million people by enhancing groundwater recharge, improving water security, and stimulating the rural economy.

Continuous monitoring over six years confirms that treated wastewater, and surface water meets NGT, 2019 standards and groundwater meets the water quality criteria for irrigation as per IS:11624-1986, BIS Standard, with no negative impacts such as heavy metals. This is largely because, Bengaluru's wastewater, being predominantly domestic, poses minimal chemical contamination risks. It should be noted that that wastewater generated in Bengaluru is predominantly domestic sewage (as mandated by law), and hence there is very low likelihood of heavy metal contamination in the first place or its transport, even if it had accidentally entered this stream it would have been taken care of as the wastewater under goes a five-layered purification process such as

(1) an anaerobic decomposition during travel to STPs which precipitates heavy metals and transfers them to the sludge, even if they ever enter this stream accidentally

(2) a retrofitted aerobic sewage treatment system which meets the stringent discharge standards set by the NGT—the STPs ensure removal of most of the household chemicals including domestic surfactants

(3) when the treated wastewater travels a distance of 53 km in the closed pipe from STP to Kolar region taking about 22h, any residual organic compound gets biodegraded,

(4) the treated wastewater undergoes over 10–60 days of residence time in contact with an algal system in an open waterbody (tank/lake/kere) functioning like a polishing pond,

(5) finally, the treated wastewater filters through tens of meters of soil contact before recharging groundwater. This gives the resident micro-organisms ample time to degrade any biodegradable compound that has escaped the earlier four stages. Further, the groundwater quality is also improved by diluting the hard groundwater with soft water (recharge water) as the added treated wastewater acts as a diluent reducing the ill effects of high fluoride and dissolved solids content of the deep aquifer groundwater, which was the case before the implementation of this project.

Extensive IISc studies clearly confirm no adverse effects of indirectly recharged groundwater on soil, crops, livestock, or public health. The cost–benefit analysis indicates a benefit-to-cost ratio of ~4.34, demonstrating significant economic returns. The project has led to improved groundwater levels, revived agriculture, reduced eucalyptus plantations, and reversed outmigration of youth who have now returned to farming, floriculture, horticulture, dairy, and fisheries. Enhanced water availability has also improved sanitation-hygiene practices, and rural livelihoods. Overall socio-economic status has shown a positive impact.

The K&C Valley initiative is now recognized as a model of circular water economy and resilience, demonstrating safe and sustainable reuse of treated wastewater for groundwater recharge. The project is regularly monitored by a national expert committee including Prof. Shyam R. Asolekar from IIT Bombay, Prof. Makarand Ghangrekar from IIT Kharagpur and Dr. Sanjeev Goyal from CSIR-NEERI, Delhi. Prof. Makarand Ghangrekar inspected the site for the whole day and *"appreciated that the outcomes of this project are very interesting with positive impacts on solving one of the main problems of water scarcity. Experts opined that there is a need to build on this experience and replicate it in other groundwater-scarce areas of Karnataka and India"*. The findings of the study are being communicated and published to international peer-reviewed journals by the IISc research team. Needless to say, this is a World level exemplar appreciated by one an all.

Given the above points, the IISc team monitoring this project is of the opinion that the secondary treatedwater is adequate for the purposes of this project which aims at improving groundwater levels and quality.

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