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Spatial Distribution of Eucalyptus Plantation and its Impact on the Depletion of Groundwater Resources of Tehsil Swat Ranizai, District Malakand

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Abstract

Native to the continent of Australia, eucalyptus is a tall, evergreen tree belonging to the Myrtaceae family. Malakand district has the largest eucalyptus plantation in the province, covering an area of 22071.29ha. The present study aims to evaluate its impact on the groundwater table (GWT) in three selected union councils (UCs) of the study area, i.e., Agra, Totakan, and Kot. Both primary and secondary data support the study. The data regarding eucalyptus plantations were collected from the Malakand Forest Division. GPS was used to mark the wells' locations. The current GWT was measured in the field. Rainfall data of the study area and surrounding was acquired from the Regional Meteorological Office Peshawar. A questionnaire survey was conducted to determine the respondents' opinion of the impact of eucalyptus plantations. The study reveals that though the GWT dropped from 2000 to 2019 in the study area, the decline is more significant in the vicinity of the plantation. The GWT near the plantation in the Agra UC dropped from 39 to 60 feet, 25 to 45 feet in Totakan, and from 20 to 60 feet in Kot UC during the study period. The study reveals no significant impact of rainfall on GWT depletion. The respondents appear to be aware of the negative effects of eucalyptus plantations on the GWT, agriculture, and biodiversity. The study concludes that, while considering community interests, there is a critical need for research to investigate and quantify the site-specific effects of eucalyptus on the ecosystem. The study concludes that, while considering community interests, there is a critical need for research to investigate and quantify the site-specific effects of eucalyptus on the ecosystem. The Eucalyptus will be able to continue fending off the rising deforestation and demand for fuel until then.

Keywords: Eucalyptus Plantation, Groundwater table, Geospatial analysis, Interpolation Malakand district, Respondent Perception

1. Introduction

Eucalyptus is evergreen tree species exotic in Pakistan. It is native to the islands of Indonesia, Papua New Guinea, and the Australian continent and is a member of the Myrtaceae family (Abbas et al., 2010; Nazli et al., 2020). It is adaptable to different types of soil and environment. Because of its rapid and unrestricted development, eucalyptus is the most widely planted tree in the world. Some of its traits include short rotation, drought tolerance, general use, and significant economic benefits (Zhang et al., 2007; Laclau et al., 2010).

Eucalyptus plantations and their impact on water resources is a contentious issue. For the keywords "Eucalyptus with water," Google Scholar shows 591,000 hits. There is a wealth of published material about eucalyptus and hydrology. The most frequently planted hardwood species worldwide, eucalyptus, covers 20 million hectares (Palmieri et al., 2020). For fuel wood, pulp, and timber production, it can be cultivated in various climatic and soil conditions. Eucalyptus, however, has been the subject of a heated debate over the last few decades regarding its detrimental effects on the environment and groundwater resources. The Eucalyptus plantation has repeatedly been accused of consuming excessive water, which has led to the loss of groundwater supplies and a decrease in soil moisture. Eucalyptus is believed to use more water than other plants. According to estimates, eucalyptus plants may absorb 50 to 90 liters of water each day. Studies by Forsyth et al. (2004), Richardson and Rejmanek (2011), Dye (2013), Cavaleri et al. (2014), Swaffer & Holland (2015), Le Maitre et al. (2015), Bayle (2019), Mattos et al. (2019), and Nazli et al. (2015) all raise concerns regarding the effects of eucalyptus plantations on groundwater supplies (2020).

Due to their high rate of evapotranspiration, eucalyptus species need more water than indigenous tree species (Zahid et al., 2010; Enku et al., 2020). In order to improve the environment, eucalyptus is widely considered and employed as an engineering solution to permanently wet and saline terrain (Bilal et al., 2014a). The eucalyptus plantation does, however, have some drawbacks. One of Eucalyptus' most detrimental traits is its massive water-pumping from subsurface aquifers (Whitehead & Beadle, 2004; Zahid & Nawaz, 2007; Christina et al., 2017; Amazonas et al., 2018). A study conducted in 21 villages in the Kolar district of Karnataka, India, examined the effects of a 20-year Eucalyptus plantation on the water table. Due to their high rate of evapotranspiration, eucalyptus species need more water than indigenous tree species (Zahid et al., 2010; Enku et al., 2020). In order to improve the environment, eucalyptus is widely considered and employed as an engineering solution to permanently wet and saline terrain (Bilal et al., 2014a). The eucalyptus plantation does, however, have some drawbacks. One of Eucalyptus' most detrimental traits is its massive water-pumping from subsurface aquifers (Whitehead & Beadle, 2004; Zahid & Nawaz, 2007; Christina et al., 2017; Amazonas et al., 2018). A study conducted in 21 villages in the Kolar district of Karnataka, India, examined the effects of a 20-year Eucalyptus plantation on the water table. According to the study, over the past 20 years, the depth of the water table has decreased from 177 meters to 260 meters. The study also finds a negative association between the distance from the eucalyptus plantation and the depth of the water table. During the study time, the water yield declines from 35 to 40% (Joshi & Palanisami, 2011).

Olaleye & Sekaleli (2011) assessed the water usage in three different land-use types in Lesotho, Africa. According to the study, water is consumed in eucalyptus plantations at a rate of 3.37 percent per day, in native forests at a rate of 1.6 percent, and in grasslands and rangelands at a rate of 1.5 percent. Additionally, due to the eucalyptus plantation, the soil moisture content is decreasing by 3.37% daily. The eucalyptus tree has a built-in system for utilizing water lavishly (Tadesse & Tafere, 2017; Mhiret et al., 2019). According to Zahid et al. (2010), Indian Mulberry (Morinda Lucida Benth), Babool (Acacia nilotica), Siris (Albizia procera), Eucalyptus, and Neem (Azadirachta indica) all consume different amounts of water. Olaleye & Sekaleli (2011) assessed the water usage in three different land-use types in Lesotho, Africa. According to the study, water is consumed in eucalyptus plantations at a rate of 3.37 percent per day, in native forests at a rate of 1.6 percent, and in grasslands and rangelands at a rate of 1.5 percent. Additionally, due to the eucalyptus plantation, the soil moisture content is decreasing by 3.37% daily. According to Zahid et al. (2010), Indian Mulberry (Morinda Lucida Benth), Babool (Acacia nilotica), Siris (Albizia procera), Eucalyptus, and Neem (Azadirachta indica) all consume different amounts of water. Olaleye & Sekaleli (2011) assessed the water usage in three different land-use types in Lesotho, Africa. According to the study, water is consumed in eucalyptus plantations at a rate of 3.37 percent per day, in native forests at a rate of 1.6 percent, and in grasslands and rangelands at a rate of 1.5 percent. Additionally, due to the eucalyptus plantation, the soil moisture content is decreasing by 3.37% daily. The eucalyptus tree has a built-in system for utilizing water lavishly (Tadesse & Tafere, 2017; Mhiret et al., 2019).

According to Zahid et al., (2010), a one-year-old Eucalyptus plantation uses 149.27 litres per day, which is more than three times as much as a Babool (58.30 litres) or Neem plantation (58.30 litres) and almost twice as much as an Indian mulberry plantation (82.84 litres) (51.57 L). Eucalyptus evapotranspiration was estimated by Hafeez & Bashrat (2003) to be 70 L/day.

Bilal et al., (2014b) reported similar outcomes in the Malakand district. According to them, the groundwater table in the area around the eucalyptus plantation is declining by 2.49 feet annually. Due to the excessive water use by eucalyptus plantations, the water table in some villages, including Totai, dropped as low as 65.97 feet. According to the study's findings, the establishment of the eucalyptus plantation has a negative impact on the surface and groundwater resources of the Malakand district. In contrast to the aforementioned findings, Lima (1984) contends that Eucalyptus cannot be blamed for groundwater depletion because its roots rarely descend below 9 to 12 feet. According to reports by Poore & fries (1985) and Abbasi et al., (2004), annual evapotranspiration from pine and eucalyptus plantations is similar. Rao (1985) noted that eucalyptus is one of the most effective consumers of scarce water, and it produces more timber per unit of water consumed than several other native species. According to Doody et al., (2011) and Cavaleri et al., (2014), the evapotranspiration rates of native Eucalyptus and invasive willow species (Salix) were comparable.

In Pakistan, the eucalyptus species were introduced in the 1980s and planted over millions of hectares of land (Zahid & Ahmad, 2002; Nazli et al., 2020). As a defense against salinity and waterlogging, the area under the eucalyptus plantation has grown recently (Singh & Dhakad, 2018). Due to its numerous socioeconomic benefits for the local populations, it is grown in practically all Pakistan provinces. Eucalyptus's socio-economic and environmental benefits include providing fuel wood, mitigating soil erosion, providing habitat for wildlife, assisting in the mitigation of climate change, etc. Using marginal land for Eucalyptus plantations and raising timber yield, social forestry was initiated in the Malakand district in 1987 with the aim of improving the socioeconomic condition of the community. In the Malakand-Dir region, almost 14.72 million Eucalyptus trees are growing in a plantation that covers 22,071.29 hectares (Bilal et al., 2014a). The largest Eucalyptus plantation in Khyber Pakhtunkhwa is located in the Malakand district.

In addition to the water table being depleted, numerous springs and wells in the Malakand district have already dried up. In 1985, Mr. Hassan Iqbal Waraich filed a writ under article 199 of the constitution of the Islamic Republic of Pakistan over environmental degradation and the detrimental effects of eucalyptus. As a result, the court's order prohibiting the scientific management of eucalyptus has been in place since 1985 (PFI, 2019). Similarly, the Bangladeshi government not only banned eucalyptus plantations but even ordered the removal of certain existing plantations due to their excessive water usage, decreased soil fertility, and detrimental impacts on wildlife (Hossain, 2003). In light of this, the objective of the current study is to map the spatial distribution of the Eucalyptus Plantation in the district Malakand and its impact on the groundwater resources.

2. Study Area

The Malakand district is surrounded by mountains covered by lush green vegetation. Malakand district was established in 1970 as a provincially managed tribal territory. In the past, it had been a tribal region that was a part of the Malakand agency and was known as the Malakand protected area. It is located between 34° 22′ 02″ and 34° 40′ 00″ North latitudes and 71° 10′ 37″ and 72° 14′ 45″ East longitudes. The Malakand district encompasses a total area of 952 km^2. It is bounded by a range of mountains on the northeast and west, separating it from district swat and Bajaur and Mohmand districts, respectively (Khan et al., 2017). Malakand district is bordered on the north by lower Dir, on the east by Mardan, and on the southwest by Charsadda and Mohmand districts. The district is divided into two tehsils. Sam Ranizai and Swat Ranizai. Sam Ranizai is generally cultivable with a negligible hilly region, while Swat Ranizai is primarily a hilly area (Barkatullah & Ibrar, 2011). The study area comprises three union councils, Agra, Totakan, and Kot. These union councils (UCs) are situated northwest of the district. The selected UCs have the largest Eucalyptus plantation in the district. The study area's location is depicted in Figure 1.

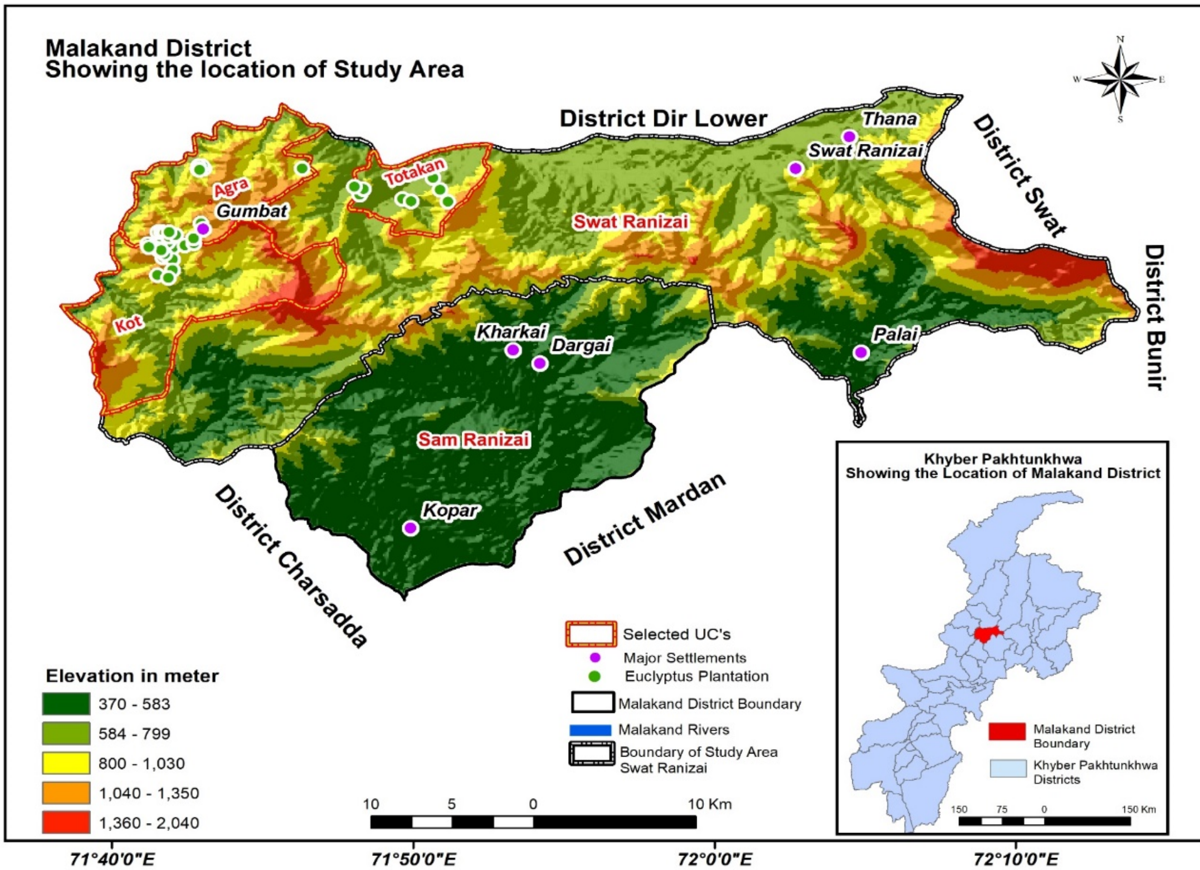

Fig. 1. Malakand district showing the location of study area, union council Agra, Totakan, and Kot.

3. Material and Methods

3.1 Data Collection and Analysis

Both primary and secondary data support the study. The data regarding the Eucalyptus plantation was acquired from the Malakand Forest Division office in Batkhela, Khyber Pakhtunkhwa. The data acquired was tabulated with XY coordinates of the plantation and the area under the plantation. To evaluate the impact of Eucalyptus plantation on the groundwater table, the data was imported in the ArcMap 10.5 environment, displayed as an event layer, and subsequently saved as a GIS point shape file. The Euclidean distance zones of 1Km, 2, 3, 4, 5, 6 and 7Km were created around the plantation and were subsequently displayed on top of the wells data, and the groundwater table for each zone was extracted.

The wells' locations were marked as waypoints using a Magellan Triton 1500 GPS. The current water table was measured on the spot in the field with the help of a string; to one end of the string, a small weight was tied (a metal nut). The string was lowered into the well, and when the weight hit the water, one could feel a slight slack in the string tension, and also, the wave appeared in the water suggesting the weight hit the water. The string was then measured with the help of measuring tape. But in most cases, the locals knew the water table and let us know the water level depth. The location of the well was also marked with the help of GPS. The data regarding water level in the past, i.e., 2000, was collected by inquiring from the tube well operator or respondents. The XY coordinates were then imported, displayed as an event layer, and saved as a GIS point shape file. The data were interpolated by the Kriging interpolation method to create a continuous surface for the groundwater table. The interpolated water table layer is then reclassified into various classes. Finally, the change in the water table was calculated by subtracting the water table in 2019 from the water table in 2000.

The primary data regarding respondents' perception of the impact of eucalyptus plantations on the GWT, trends, patterns, the GWT in the past, the number of wells, springs that dried up, etc., were collected using a questionnaire survey. The valley boundary was extracted from the Digital Elevation Model (DEM) of the study area to exclude the higher mountainous area from the analysis. Figure 2 shows the flow chart of data processing and analysis, which will be followed to achieve the study objectives. The analysis was carried out in ArcMap 10.5.2.

Since there is no meteorological station in the study area, the 30-year (1988-2016) rainfall data for the 04 nearby metrological stations was acquired from the regional meteorological office in Peshawar. The data was collected for the meteorological station of Chitral (district Chitral), Dir Upper (district Dir Upper), Timergara (district Dir Lower), and Saidu Sharif (district Swat). The acquired data were utilized to evaluate and quantify changes in the amount of rainfall and to ascertain whether or not the rainfall has any role in groundwater table (GWT) depletion. The rainfall data was divided into two halves from 1988 to 2001 and 2002 to 2016, and the average annual rainfall was computed for each station for both periods. The data were then interpolated using the ArcMap Spatial Analyst interpolation tool, and a continuous surface was generated using Kriging interpolation. The interpolated surface for both periods (1988-2001 and 2002-2016) was compared for variation in rainfall.

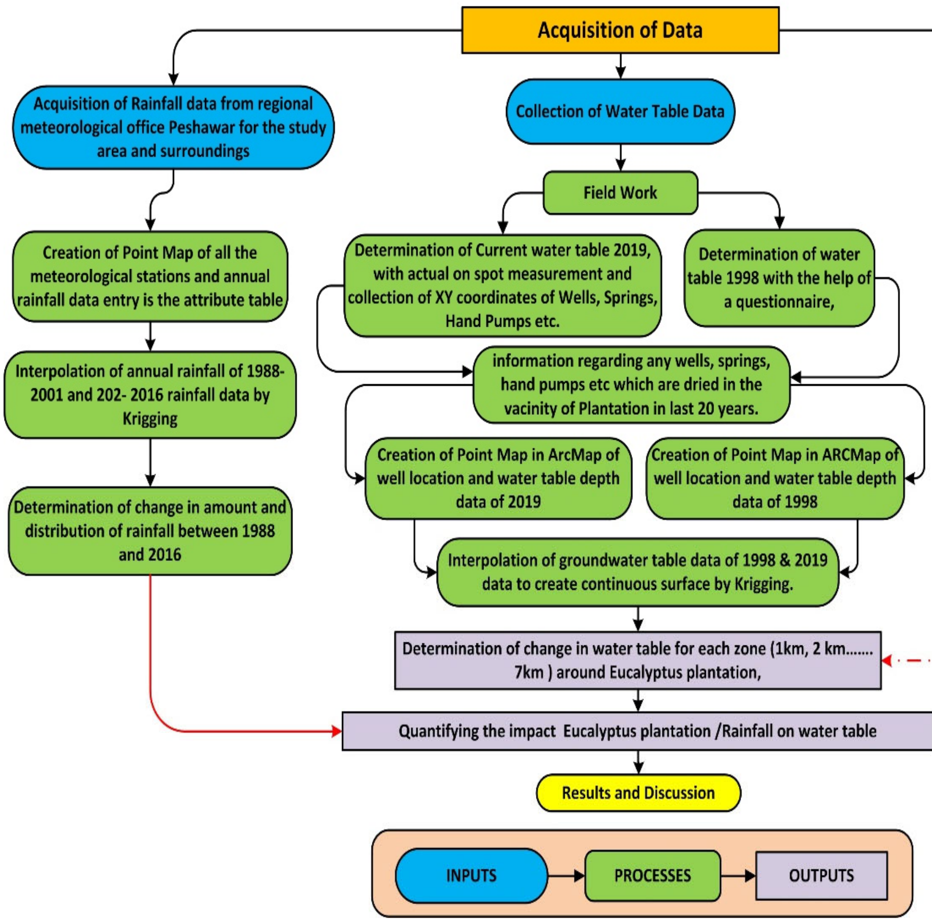

Fig. 2. Showing the flow chart of data processing and analysis.

4. Results and Discussion

4.1 Area under Eucalyptus plantation

The area under the Eucalyptus plantation in the selected union councils is shown in figure 3 and table 1. The analysis suggests that the Totakan UC has the largest Eucalyptus plantation. Out of the total 1394.31 ha vegetative area, the Eucalyptus plantation accounts for 83.84%. Agra UC accounts for 160 ha and Kot UC 120 ha, representing 5.85% and 4.50% of the total vegetation area, respectively. In all three UCs, 21.34% of the total vegetation area is under the Eucalyptus plantation (Hussain, 2002; Malakand Forest Division, 2019). The main reason the largest plantation in Totakan UC is the smallest area under natural vegetation is to fulfil the demand for fuel wood; inhabitants rely on Eucalyptus plantations.

Table 1. Area under Eucalyptus plantation in selected union councils.

Union Council Name	Area under Eucalyptus Plantation in ha	Total Vegetation Area in ha	Eucalyptus % age of Total Vegetation Area
Totakan U.C.	1169	1394.31	83.84
Agra U.C.	160	2726.67	5.87
Kot U.C.	120	2667.36	4.50
Total	1449.00	6788.34	94.21

*Source: Malakand Forest Division office Batkhela, Khyber Pakhtunkhwa.

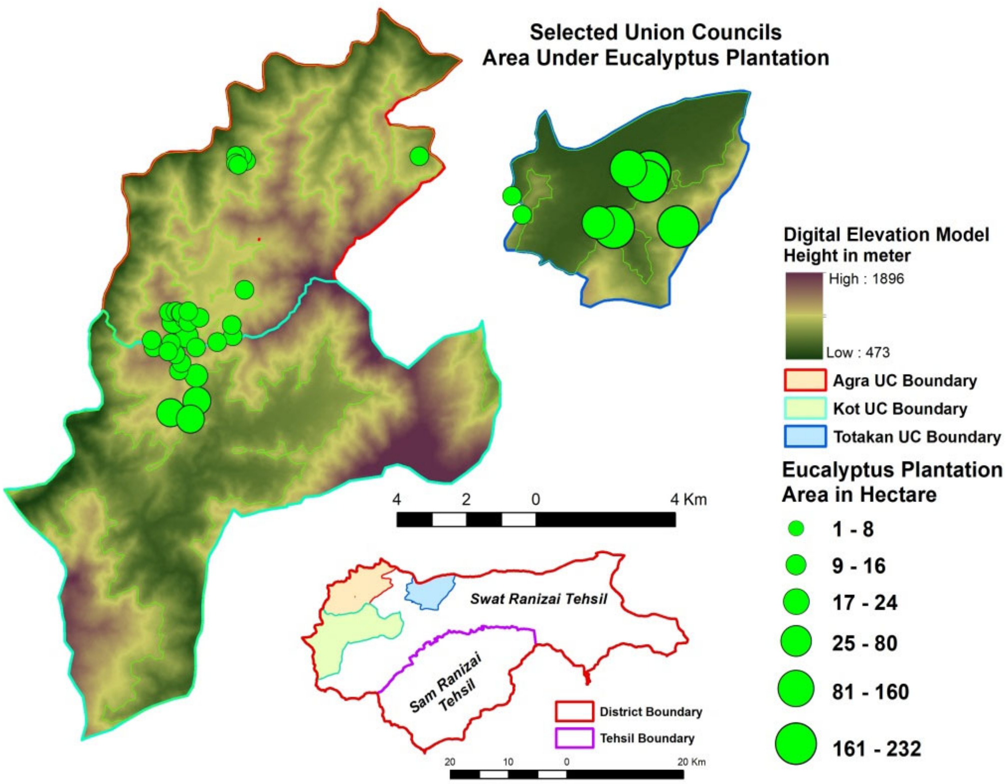

Fig. 3. Area under Eucalyptus Plantation in Selected Union Councils of Malakand District.

4.2 Impact of Eucalyptus plantation on groundwater Table

The water uptake by Eucalyptus plantations is an essential issue throughout southeast Asia and China (Liu et al. 2017; Wang et al. 2019; Ren et al. 2019; Arnold et al. 2020). The main criticism that has been launched against the Eucalyptus plantation is that they deplete the groundwater table and that on sloping watersheds, they do not regulate the water flow (FAO 1985). Engel (2005) found that the Eucalyptus plantation utilized groundwater (67% of its total water use) and water from the upper vadose zone, which is the primary source of aquifers recharge. The study also found that a 40-hectare Eucalyptus plantation creates a steeper hydraulic gradient, forcing the surrounding water to enter the plantation area.

The analysis of the data collected reveals that in most of the areas in all three union councils, the water table went down. In the Agra union council, the Eucalyptus plantation is concentrated in the middle and southern parts of the UC. The water table in these areas descended from 39 to 60 feet in the last 19 years. The respondents attributed this decline in the water table to the presence of the Eucalyptus plantation. Figure 4A and 4B show the water table from 2000 and 2019, and figure 4C shows the change in the water table from 2000 to 2019 of Agra UC. Figure 5 shows the groundwater table from 2000 to 2019 and the change in the water table from 2000 to 2019 in various settlements of the Agra Union council.

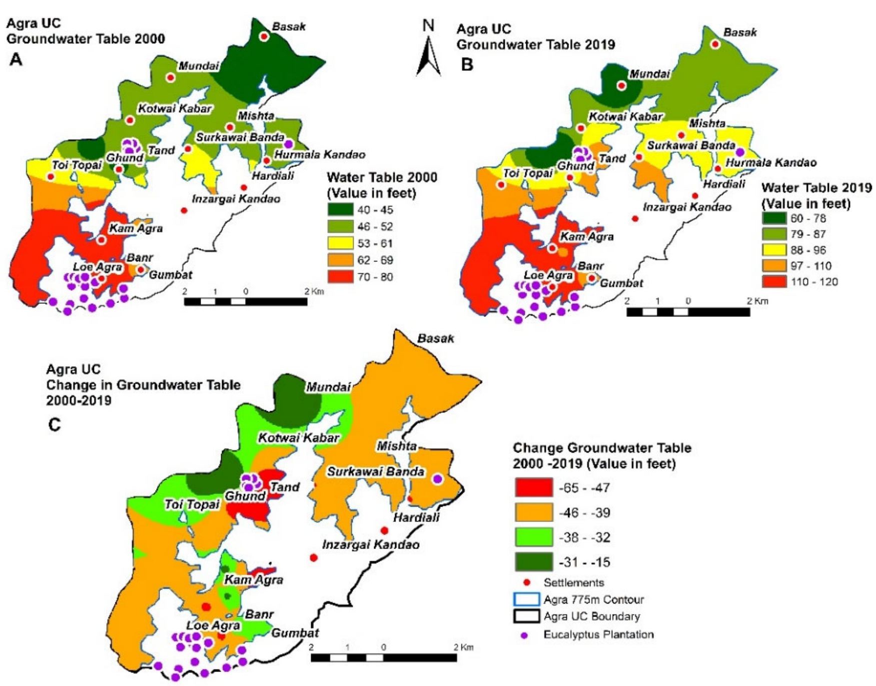

Fig. 4. A) Shows the water table 2000, B) water table 2019 and C) change in water table from 2000 to 2019 in Agra Union council.

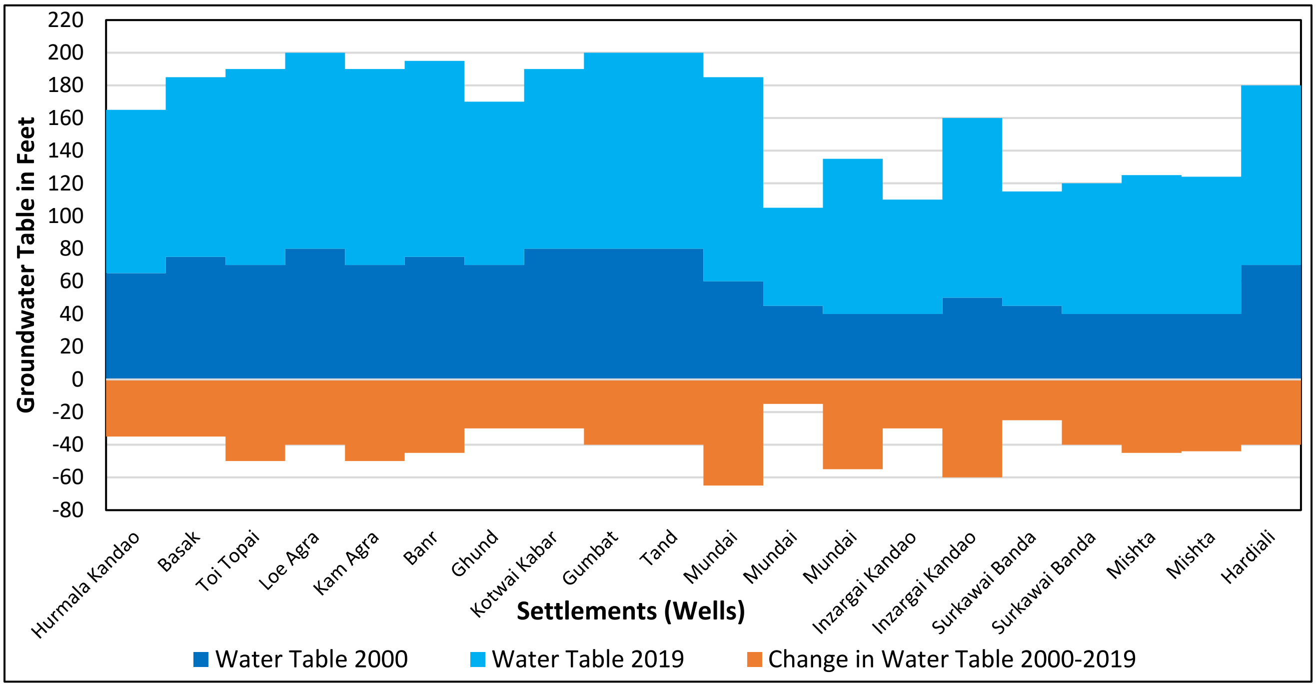

Fig. 5. Showing the groundwater table 2000, 2019 and changes in water table from 2000 to 2019 in various settlements of Agra Union council.

In Kot UC, the Eucalyptus plantation is located in the northeastern part of the UC. The analysis suggests that the water table in the vicinity of the plantation has gone down from 39 to 60 feet in the last 19 years. Figure 6A shows the water table from 2000 and 2019, and figure 6B shows the change in the water table from 2000 to 2019. In contrast, figure 6C shows the change in groundwater table 2000- 2019 for all the three selected union councils of tehsil Swat Ranizai. Figure 7 shows the groundwater table from 2000 to 2019 and the change in the water table from 2000 to 2019 in various settlements of Kot Union council.

In the Totakan union council, the northeastern part has a lower water table because of the closeness to the river Swat. Most of the Eucalyptus plantation is located toward the southwestern part of the union council. The water table in the vicinity of the plantation has decreased in the last 19 years. The overall decline in this area is from 25 to 45 feet. Figure 8A and 8B show the water table from 2000 and 2019, and figure 8C shows the change in the water table from 2000 to 2019. Figure 9 shows the groundwater table from 2000 to 2019 and the change in the water table from 2000 to 2019 in various settlements of the Totakan Union council.

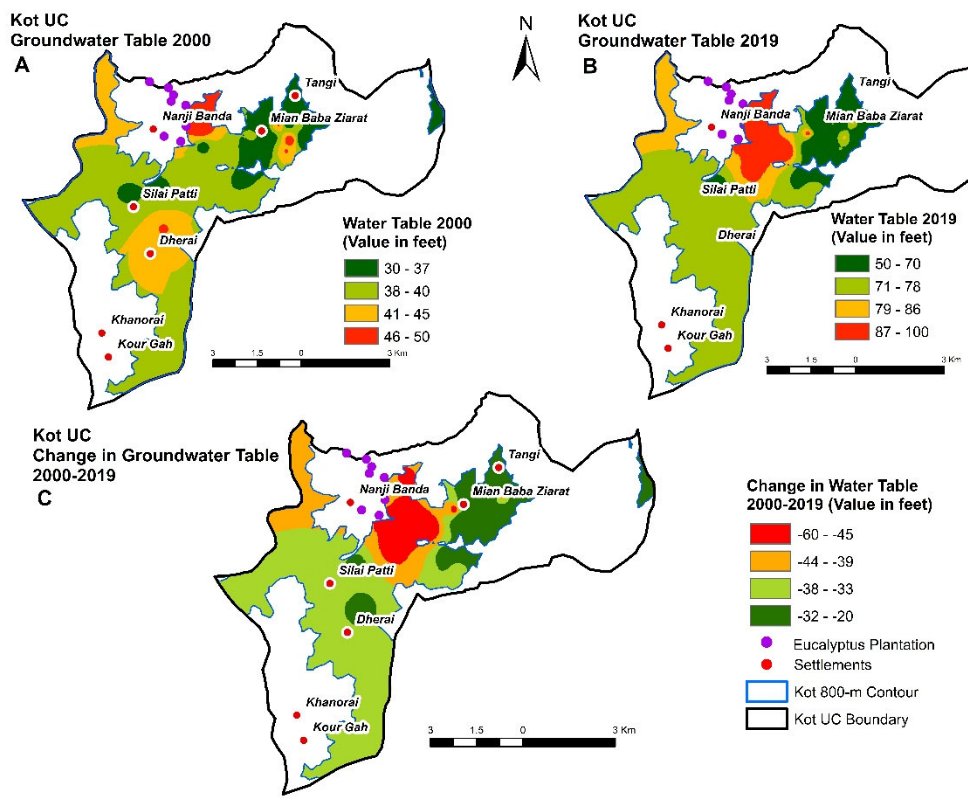

Fig. 6. A) Shows the water table 2000, B) water table 2019 and C) change in water table from 2000 to 2019 in Kot Union council.

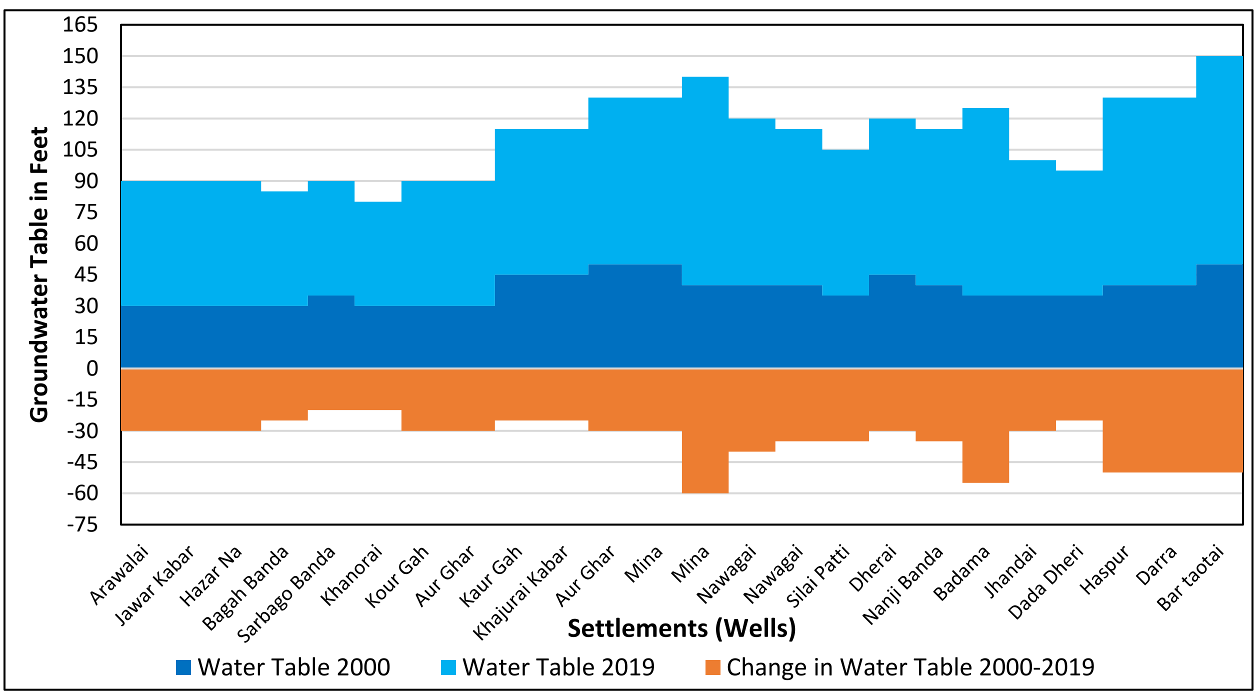

Fig. 7. Showing the groundwater table 2000, 2019 and change in water table from 2000 to 2019 in various settlements of Kot Union council.

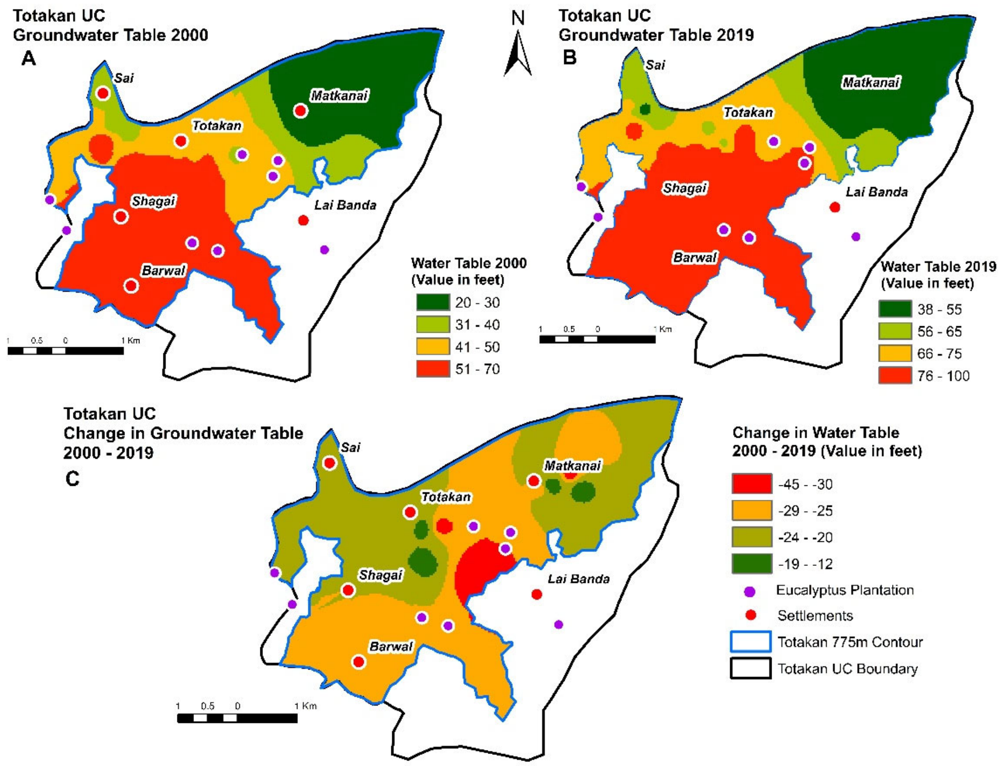

Fig. 8. A) Shows the water table 2000, B) water table 2019 and C) change in water table from 2000 to 2019 in Totakan Union council.

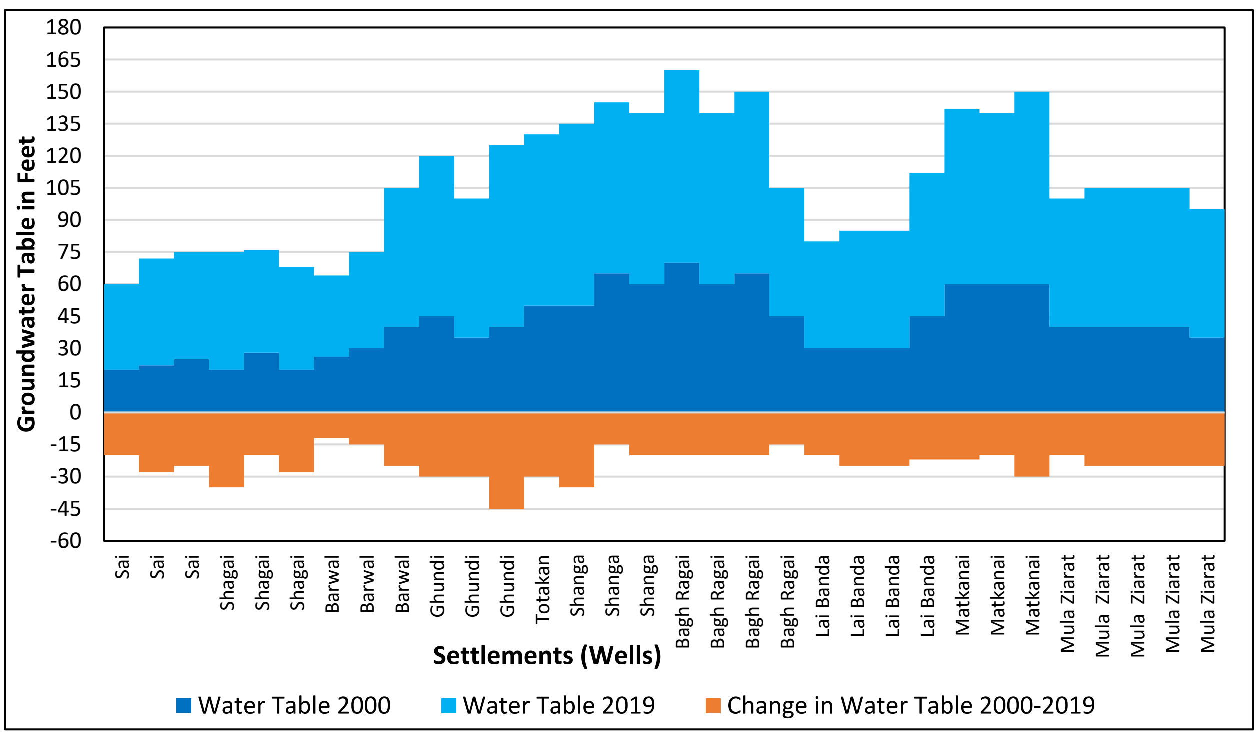

Fig. 9. Showing the groundwater table 2000, 2019 and change in water table from 2000 to 2019 in various settlements of Totakan Union council.

To analyze the impact of distance from the Eucalyptus plantation on the lowering of the groundwater table, Euclidian distance zone of 1km, 2,3,4,5,6, and 7km were created around the plantation and overlaid on the groundwater table layer. The analysis reveals that the distance from the Eucalyptus plantation negatively correlates with the groundwater table's depth. Figure 10 and Table 2 show the change in water table 2000-2019 in various distance zones from the Eucalyptus plantation, while figure 12 is the pictorial representation of the same data. The average decline in the water table is 44.25, 38.6, 32.1, 25.85, and 26.2 feet in 1km, 2km, 3km, 4km, and 5km radius of the plantation, respectively. In terms of percentage decline in the groundwater table, the analysis reveals an average 123.10 % decrease in the groundwater table is observed within 1km of the Eucalyptus plantation. Similarly, 72.37%, 69.39, and 69.50% decline in the water table is reported within a 2km, 3km, and 4km radius of the plantation, respectively. The analysis further reveals that the decline in the water table is more marked in the Kot Union council. Figure 11 and Table 3 depict the percentage decline in the water table concerning distance from the plantation.

The fieldwork also confirms the drying of 8 wells in Agra UC and 4 in Totakan UC. In addition to one hand, a pump and five springs were also reported to dry in Totakan UC. Figure 11 shows the study area's dried wells, a hand pump, and springs. The analysis reveals that dried wells, springs, and a hand pump are mostly located within a 2-3 km radius of the Eucalyptus plantation. The results are in line with the studies carried out by Bilal (2014), Khan and Hasan (2007), and Zahid and Nawaz (2007) in various areas of Pakistan.

According to Bahuguna (1984), Eucalyptus consumes more water than other trees, and the streams and springs in the vicinity of the Eucalyptus plantation went dry as a result of its high water uptake. Dabral & Raturi (1985) and Chaturvedi et al., (1984) claimed that the area with the same number of Eucalyptus plants consumed more water than any other hardwood species. A study by Joshi and Palanisami (2011) indicates that a bore well within a distance of one km from the Eucalyptus plantation yields 35-42% less water compared to the wells located 2-3 km from the plantation. Brites (2013) states that the Eucalyptus plantation significantly impacts the groundwater table. He observed 32 to 52 feet lowering of the groundwater table during 13 years in the vicinity of the Eucalyptus plantation. Ram et al., (2011) also blamed the Eucalyptus plantation for lowering the groundwater table. They reported 2.78 feet lowering of groundwater table in the vicinity of the Eucalyptus plantation due to its luxurious water use. Besides, it is reported by various studies show that its roots can grow up to 30 feet to extract more water (Joshi & Palanisami, 2011). The roots of the Eucalyptus plant make a dense network just below the earth's surface to extract every drop of moisture, resulting in reduced water availability and depletion of the groundwater table (Zegeye, 2010; Maier et al., 2017; Mattos et al., 2019). The Economic and Planning Council Karnataka (EPCK) also agrees with the fact that Eucalyptus is a lavish consumer of water (Hoogar et al., 2019). The same results have been communicated by Zahid and Nawaz (2007). According to them, the transpiration coefficient and water use efficiency of Dalbergia Sissoo (*Shisham*) is 0.89 and 7.94 gL-1 compared to 0.93 and 4.06 gL-1 for Eucalyptus. The study concludes that increased water use by Eucalyptus may lead to a lowering of the groundwater table and depletion of aquifers' water resources in arid and semi-arid Pakistan. In Pakistan's environment, Eucalyptus consumes three times more water than Australia due to higher vapor pressure deficiency (Morris et al., 2006). According to Khan and Mahmood-Ul-Hasan (2007), the Eucalyptus plantation in Udigram, Swat valley, Pakistan, is responsible for the depletion of groundwater resources, leading to the drying of wells, decreasing the flow of springs, and drying of spring.

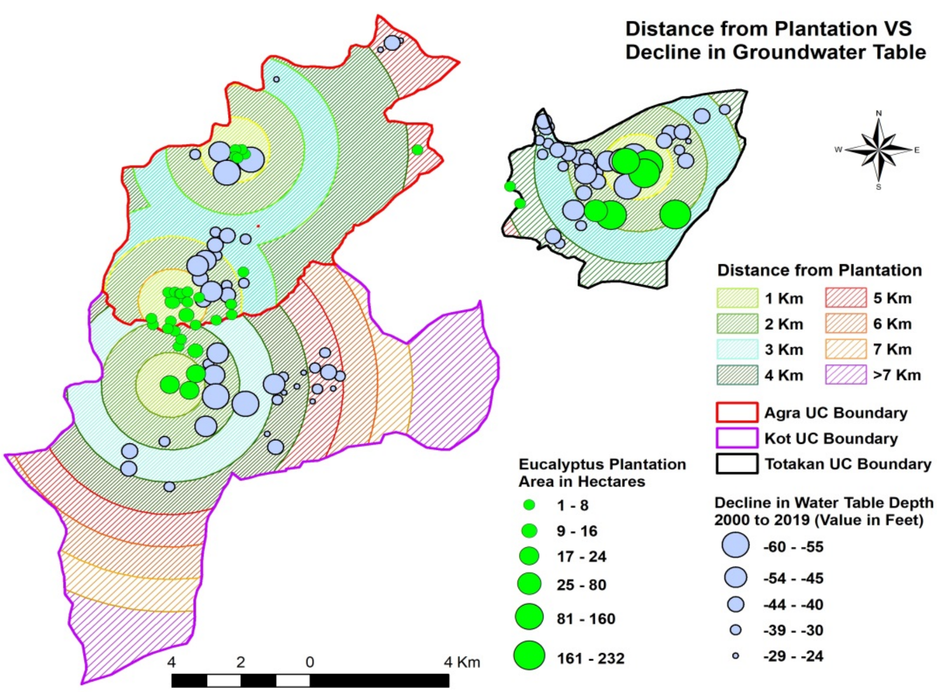

Fig 10. Selected Union Councils Changes in Water Table 2000-2019 VS area under Eucalyptus Plantation.

Table 2. Decline in Groundwater Table depth (in feet) within various distance zones of the Plantation.

Name of UC	Distance From Plantation				
	1 km radius of the Plantation	2 km radius of the Plantation	3 km radius of the Plantation	4 km radius of the Plantation	5 km radius of the Plantation
Agra	47.5	41.0	31.0	-	24.4
Kot	-	50.0	42.6	30.0	28.0
Totakan	41.0	24.8	22.7	21.7	-
Average	44.25	38.6	32.1	25.85	26.2

*Source: Analysis in ArcMap 10.5

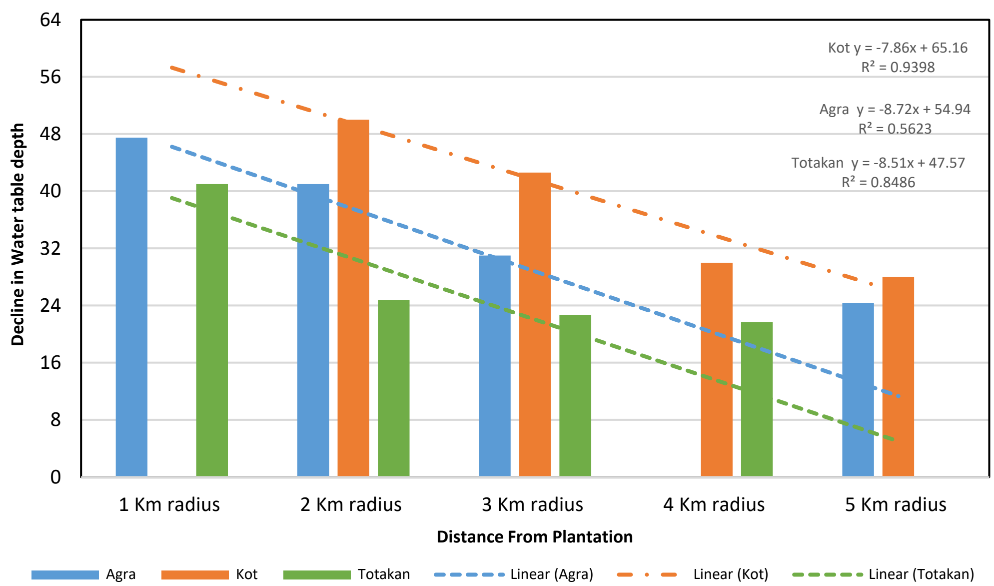

Fig. 11. Decline in Groundwater Table depth (in feet) with respect to distance from Plantation.

Table 3. Percentage decline in groundwater table depth within various distance zones of the plantation.

Name of UC	Distance From Plantation				
	1 km radius of the Plantation	2 km radius of the Plantation	3 km radius of the Plantation	4 km radius of the Plantation	5 km radius of the Plantation
Agra	146.0	54.75	48.91	-	74.0
Kot	-	104.0	101.25	83.0	81.75
Totakan	100.2	58.35	58.0	56.0	-
Average	123.10	72.37	69.39	69.50	77.88

4.3 Community perception of Eucalyptus effect on groundwater Level

The biggest environmental risk is climate change, which causes widespread weather changes (Eslamain, 2014). Groundwater level depletion has become more variable in recent decades as a result of rising global water demand and climate change's consequences (Eslamain, 2014). During the present study, the community perception regarding the impact of the Eucalyptus plantation on the groundwater level was also probed. The majority of respondents in all three selected union councils unanimously agreed that the Eucalyptus plantation lowered the water table specifically in the vicinity of the plantation. The survey results are shown in Table 4. The analysis of the table reveals that almost all the respondents in UC Agra and Totakan unanimously believe that Eucalyptus is a more water-consuming plant as compared to other local species such as mulberry *(toot*), *Melia azedarach* (Bakaen*), Dalbergia Sissoo (*Sheesham*),* and poplar (Sufaida*)*. The survey results suggest that respondents of Totakan and Agra UC are well aware of the fact that the Eucalyptus is one of the highest water-consuming plants. However, in Kot UC, only 40 % of the total respondents believe and considered Eucalyptus as one of the highly water-consuming plants, while the remaining 60% believe otherwise; this may be because the rate of water consumption by Eucalyptus plantation varies from place to place and time to time (Fitene & Deck, 2004).

Table 4. Community perception about Eucalyptus effect on groundwater Level.

Response		No. of respondents	Total percentage
Agra Union Council			
1	Yes	97	100
2	No	00	00
Totakan Union Council			
1	Yes	104	100
2	No	00	00
KOT UC N 105			
1	Yes	42	40
2	No	63	60

*Source: Field Survey

4.4 Rainfall and temperature variations

The rainfall variability, both seasonal and spatial distribution, is being predicted for Asia (IPCC, 2007). A decreasing trend in rainfall amount and pattern is predicted for Pakistan's coastal and semi-arid regions. The rainfall data for the last 28 years (1988-2016) was acquired from Regional Meteorological Office Peshawar. Unfortunately, there is no meteorological station in the study area; therefore, the data on rainfall was collected from meteorological stations of Saidu Sharif (District Swat) Chitral Town (District Chitral), Timergara (District Dir Lower), and Dir (District Dir Upper). The Timergara (Dir Lower) was established in 2008, and the data is only available for ten years. All these stations are located in the surroundings of the study area and have the same physical characteristics as that of the study area.

Data were plotted in excel to calculate the annual rainfall's temporal trend, and a linear trend line was calculated. The interpolation of rainfall reveals that the rainfall in the study area Swat Ranizai decreases from 1141-1160 mm to 1091-1112 mm between the two time periods 1988-2001 and 2002-2016. Figure 12 shows the rainfall variability in the Malakand division and study area. A decreasing trend in overall rainfall is observed for all the meteorological stations.

The trend analysis for rainfall data of 4 meteorological stations for annual rainfall shows variations. Figures 13A, B, C, and D show the trends of rainfall for Dir (district Dir Upper), Chitral (district Chitral), Saidu Sharif (district Swat), and Timergara (district Dir Lower), respectively. It is clear from the results that the trend in the rainfall in all four meteorological stations is negative, and slopes are decreasing for all the stations. The analysis suggests that rainfall in the study area is declining, which may cause the groundwater table's lowering. Decreasing rainfall can reduce the aquifer recharge capacity so that the water table may be lowered. However, the analysis based on the distance from the plantation suggests that rainfall has a minimum impact on the decline of the water table in the study area.

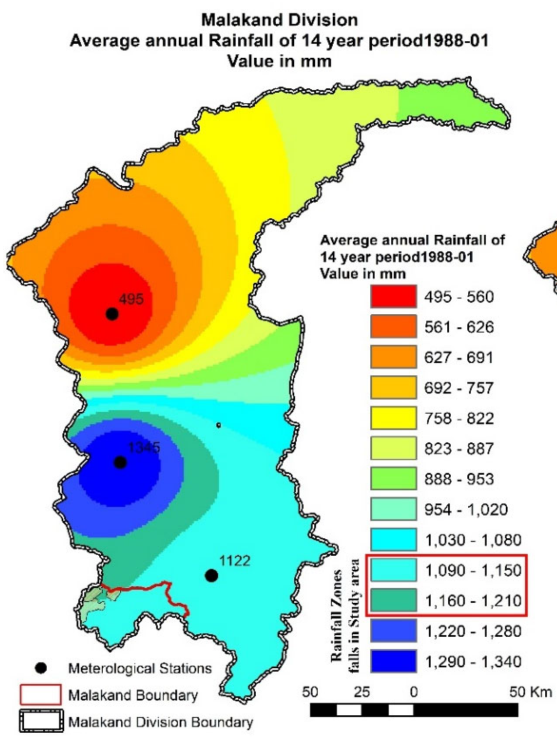

Fig. 12. The amount and spatial distribution of rainfall in the study area.

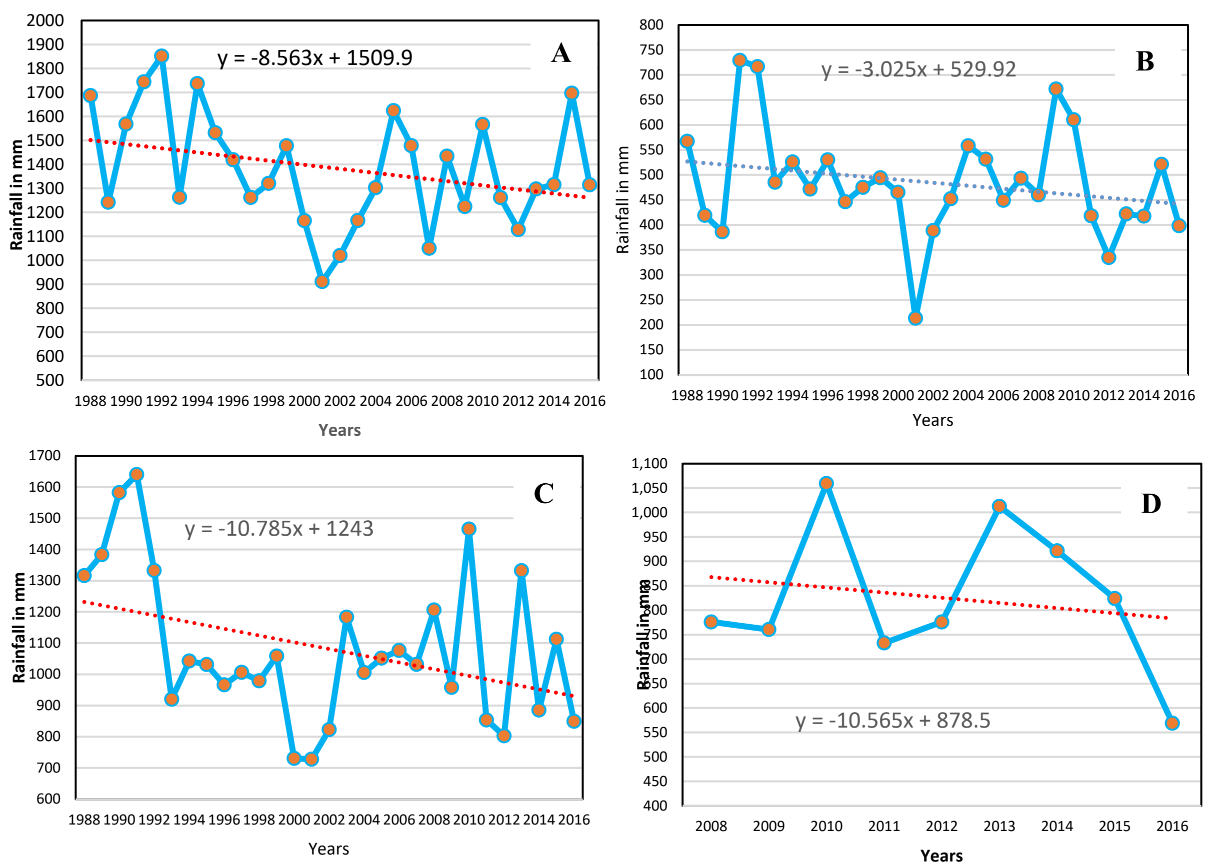

Fig. 13. The average annual rainfall and trend 1988-2016. **A,** Dir (Dir Upper) **B,** Chitral (Chitral) **C**, Saidu Sharif (Swat) **D,** Timergara (Dir Lower).

5. Conclusion

The present study concluded the detrimental impacts of Eucalyptus on groundwater resources of the Malakand area. Google Scholar displays more than 591,000 results for Eucalyptus and water and 29,800 for Eucalyptus and groundwater. Researchers quantitatively studied the effects of Eucalyptus plantation on soil quality, fertility, biodiversity, crop yield, and production and determined the negative impacts of Eucalyptus plantation. The researchers also predict the long-term damaging impacts of the Eucalyptus plantation on the environment. This research has shown that the respondents of the study area seem well aware of the ill effects of the Eucalyptus plantation on the groundwater table. The respondents unanimously attributed the lowering of the groundwater table to the increasing Eucalyptus plantation. The same is confirmed by the present study; the water table in the study area went down in the last 20 years. However, the decrease in the water table is more pronounced in the vicinity of the plantation compared to other areas. In the Agra UC, the Eucalyptus plantation is concentrated in the middle and southern parts of the UC. The water table in these areas went down in the last 19 years from 39 to 60 feet. In the Totakan UC, the northeastern part has a lower water table because of its closeness to the Swat. Most of the Eucalyptus plantation is located towards the southwestern part of the UC, and the water table in the vicinity of the plantation has gone down from 25 to 45 feet in the last 19 years. In Kot union council, the Eucalyptus plantation is located in the northeastern part of the UC. The analysis suggests that the water table in the vicinity of the plantation is gone down from 39 to 60 feet. The plantation is also blamed for drying eight wells in Agra UC and 4 in Totakan UC. Moreover, one hand pump and five springs in Totakan UC also dried in the last 25 years. In the last 30 years, the amount of rainfall in the study area decreased from 1141-1160 mm to 1091-1112 mm from 1988-2001 to 2002-2016 (14-year interval). This decreasing trend as a whole is revealed for all the meteorological stations of Malakand Division, i.e., Chitral Town (Chitral District), Dir (District Dir Upper), Saidu Sharif (District Swat), and Timergara (District Dir Lower). Though the rainfall has a decreasing trend, it may have minimal impact on lowering the water table, as shown in the spatial analysis. Despite all the ill effects, most respondents were still willing to grow Eucalyptus, which will be included in their future plantations. However, the respondents prefer to plant Eucalyptus in marginal land to provide fuelwood, etc. The Forest Department officials believe that Eucalyptus is contributing to and protecting the existing as well as newly developing plantation and natural forests by providing and fulfilling the fuel wood demand of the study area. Despite the study findings and the existing shreds of evidence well supported by literature on the negative impacts of Eucalyptus plantations on the environment, the annihilation of the plantation is not a sustainable solution. Instead, it is suggested to have a proper management plan for the growth and plantation of the Eucalyptus, specifically in irrigated agricultural areas, as part of sustainable farm forestry and waterlogged areas where these species can prove highly beneficial. With the appropriate species selection, plantation site selection, etc., efficient utilization can be maintained with little or no adverse effects on groundwater resources and the ecology of the agricultural landscape. It is simply impossible to eradicate Eucalyptus species specifically from Pakistan in general and Malakand District in particular, which have multiple economic benefits to the local communities. There is a dire need for research to test and quantify the site-specific impacts of Eucalyptus on the environment while keeping in view the community's interest. Until then, Eucalyptus can continue to combat the increasing deforestation and demand for fuelwood.

Conflicts of Interest: The authors declare no conflict of interest.

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