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The effect of water physical quality and water level changes on the occurrence and density of larvae of *Anopheles* mosquitoes around the shoreline of the Koka reservoir, Central Ethiopia

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Abstract

Entomological studies to determine the effect of the physical characteristics of larval breeding water bodies and reservoir water level changes on the occurrence of *Anopheles* mosquito larvae and on the spatial and temporal formation of larval breeding habitats were conducted in two villages at Koka reservoir between August and December 2007. Of the two study villages, Ejersa is in close proximity to the reservoir, and Kuma is 5 km away from it. Data on the type, number and physical characteristics of *Anopheles* larval breeding habitat, species composition and densities of anopheles mosquitoes in and around the study villages were investigated and recorded. Meteorological and reservoir water level data were compared with availability of *Anopheles* larval breeding sites and densities. Entomological data from the weekly larval collections showed that *Anopheles pharoensis* Theobald, *Anopheles gambiae* s.l. Giles, *Anopheles coustani* Laveran and *Anopheles squamosus* Theobald were breeding in the study area. The mean larval density of *A. gambiae* s.l. in this study was higher in slightly turbid and shallow aquatic habitats than in turbid and relatively deep aquatic habitats (F=16.97, p<0.05 and F=6.03, p<0.05, respectively). The density of *A. pharoensis* in habitat with floating vegetation and with relatively shady conditions was significantly higher than that of less shaded aquatic habitat and greater emergent vegetation (F=15.75, p<0.05 and F=10.56, p<0.05, respectively). There was also a positive correlation between the occurrence of *Anopheles* larvae with water temperature of the breeding habitat and daily minimum atmospheric temperature (r=0.541, p<0.05 and r=0.604, p<0.05, respectively). Similarly, there was a positive correlation between falling reservoir water levels and the number of positive breeding habitats at Ejersa during the sampling period (r=0.605, p<0.05). Results in this study show that physical characteristics such as water temperature, turbidity, depth and vegetation cover play an important role in the species composition, total *Anopheles* larval count, and the density of *Anopheles* mosquitoes in the vicinity. The proliferation of suitable breeding habitats around the reservoir villages is strongly associated with reservoir water level changes. This

is particularly important for *A. pharoensis* and *A. arabiensis* which are important vectors of malaria in the area. Further investigation on the species diversity, physical and chemical habitat characteristics and impact of water holding capacity of the soil need to be done to generate detailed baseline data which will serve as a basis for proper water management activities for malaria risk mitigation.

1 Introduction

In Africa, water resource development activities largely focus on dams and irrigation schemes which contribute substantially to food security, renewable energy production, and sustainable economic development. At present, Ethiopia is engaged in extensive water resource development activities and construction of dams and reservoirs for irrigation and hydroelectricity are a priority (McCartney et al., 2007). The ecological changes associated with these development activities often entail negative health impacts due to the creation of new mosquito breeding sites and thus altered human-vector-parasite contact patterns. Water impoundments in many malaria endemic parts of the country pose serious public health concerns due to increased risk of malaria transmission (Keiser et al., 2005). There is an association between malaria incidence and proximity to dams in Ethiopia. Malaria case rates among people living within 1 km of the Koka reservoir are about 2.9 times greater than for those living between 1 and 2 km from the reservoir and 19.9 times greater than for those living 5–9 km from the reservoir (Kibret et al., 2009). In Tigray malaria incidence in young children was found to be seven times higher in communities near dams than those further away (Ghebreyesus et al., 1999). A recent study in the same area showed that, the abundance of adult *Anopheles* mosquitoes in villages near dams was 5.9–7.2 times higher than those villages further away from dams (Yohannes et al., 2005).

Villages located near dams or impounded waters are thus subjected to increased malaria incidence mainly due to the presence of abundant and suitable breeding habitats for *Anopheles* mosquitoes which increases the density of the malaria vectors

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capable of transmitting the disease. Proximity to a dam includes command areas or irrigation water that can serve as *Anopheles* larval development sites. However, this general expectation is valid only if the habitat conditions created match the ecological requirements of the local vectors. In particular, it requires that the new bodies of standing water have sunlight or shade, surrounding vegetation, turbidity etc. compatible with the larval habitats for at least one local mosquito species (Minakawa et al., 1999; Shililu et al., 2003; Keiser et al., 2005).

This study was conducted to investigate the effect of physical habitat characteristics of recurrently formed *Anopheles* larvae breeding habitat, associated with the rise and fall of water in the Koka reservoir. Comparison was made between a village located near the shoreline with one located further from the reservoir. The study determined the species composition and occurrence of *Anopheles* larvae in both villages.

2 Material and methods

2.1 Study area

The Koka dam is located in the Rift Valley of Ethiopia, some 100 km south east of Addis Ababa in the Awash Basin (8° 41′ N and 39° 35′ E) at 1590 m a.s.l. (Fig. 1). The main rainy season starts in June and extends to the end of August/September, while the short rainy season occurs from March to May. The mean annual maximum and minimum temperatures are 30.4 °C and 14 °C, respectively.

The dam was the first hydropower plant in Ethiopia. It was built to generate electricity for Addis Ababa and other urban centers. However, it is now multipurpose and, in addition to electricity production it is now also used for downstream irrigation, of the 6000 ha Wonji Sugarcane Project (McCartney et al., 2007). The capacity of the Koka reservoir has declined from 1650 Mm^3 in 1959 to 1186 Mm^3 due to sedimentation over the years. The loss of total storage capacity is estimated to be 464 Mm^3, which is 28.1% of the total storage volume of the reservoir (Zewdu, 2005).

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The area is characterized by a wide and open plain, suitable for cultivation of agricultural crops. Vegetables are grown around the reservoir in the wetland created by the receding reservoir water and using diesel water pumps to extract the shallow ground water. Sparsely distributed acacia trees are common in the area.

The study was conducted at two sites located at different distances from the Koka reservoir. Site 1 is the village of Ejersa (population 2380) where the reservoir comes close to the middle of the village during the peak of the rainy season. Site 2 is the village of Kuma (population 4300), which is located five km from Ejersa and is always at least 5 km away from the reservoir, even when it is at its maximum extent. In both villages people live in traditional houses or huts called Tukuls.

In Ejersa, there are households that are located only a few meters away from the shore during the rainy season when the reservoir water levels rise. Farmers in the area are known for the production of vegetables and some cereals especially between the months July and February. Residents also fish in the reservoir during the rainy season (Plate 1). As the water recedes during the dry season they cultivate the shoreline of the reservoir (Plate 2). Recession of reservoir water also creates potential mosquito larval breeding sites, in the form of turbid shoreline puddles (Plate 3).

Kuma is located at a similar elevation as Ejersa (i.e. 1590 m a.s.l.) but 5 km away from the reservoir. It is located beyond the typical flight range of mosquitoes, where the effect of the reservoir is not apparent (Kibret et al., 2009). In this village, the breeding sites for *Anopheles* mosquitoes are temporary rain pools created by the effect of the summer rain and agricultural puddles created by the over flow of irrigation ditches in farmers fields (Plate 4).

Ten years of monthly climate data as well as the most recent two years of mean daily data were obtained from the National Meteorological Agency (NMA). These data comprised observations of minimum and maximum temperature, rainfall and relative humidity. Daily reservoir water levels for the study period were obtained from Ethiopian Electric Power Corporation (EEPCo) (Figs. 2 and 3).

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2.2 Larval sampling

Larval collection was done at the two study villages on a weekly interval over the period August–December 2007. This period was selected because it corresponds to the peak of malaria transmission in the area. Sampling was carried out between 11:00 and 16:00 LT. During each sampling period, the entire available breeding habitat within a 500 m^2 area was visited and checked for the presence of *Anopheles* mosquito larvae. In all potential breeding sites 3 samples were obtained using a standard (350 ml) dipper (Plate 5). Any larvae collected were pipetted into separate vials and taken to the Nazereth Insectary (Oromia Malaria Control Center) where they were gently heated to kill the larvae. The dead larvae were preserved in a 70% alcohol solution, prior to identification. The third and fourth instar larvae were visually sorted and processed for identification. The larvae were first mounted (using a gum chloral) on a dissecting microscope and later identified to the species level using morphological characteristics (Verrone, 1962).

2.3 Larval habitat characterization

Along with the collection of larvae, data on the characteristics of the larval breeding habitats were collected. For each positive habitat identified, water temperature was measured using a thermometer. It was lowered below the water surface and left for two minutes for the thermometer reading to stabilize (Plate 6). It was then withdrawn without touching the bulb end and the temperature was recorded (Minakawa et al., 1999; Shillilu et al., 2003; Yohannes et al., 2005). The turbidity of the larval breeding water was categorized by taking a small sample of water in a glass test tube and comparing it with a white background. Turbidity was classified as simply turbid or slightly turbid. Water depth was measured with a small-labeled stick. Other parameters, including surface area, exposure to sunlight, presence and types of vegetation and type of substratum (i.e. muddy or rocky) were observed and recorded (Minakawa et al., 1999; Shillilu et al., 2003; Yohannes et al., 2005).

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2.4 Data analysis

All the data collected on larval density, physical characteristics of breeding habitat, and relevant meteorological observations as well as reservoir water level were entered into a Microsoft Excel database system and analyzed using SPSS version 13 statistical software (SPSS Inc, Chicago, IL, USA). The X^2 test was used to compare total number of larvae in different aquatic habitats and an independent samples t test was used to analyze the relationship between mean larval densities and different physical characteristics of the habitat. Weekly changes in water levels were computed by subtracting the value of the water level at the start of the week from that at the end of the week. Descriptive statistics and bivariate correlations were used to determine the strength of association between larval density and the independent variables including atmospheric temperature (min and max), water temperature and water level.

3 Results

3.1 Larval species composition

A total of 1797 3rd and 4th instar larvae of *Anopheles* mosquitoes were collected from both study villages during the study period. Of these 1645 (91.4%) were from Ejersa and 152 (8.6%) were from Kuma. Identification of the 3rd and 4th instar larvae revealed that *Anopheles pharoensis* Theobald *A. gambiae* s.l. Giles, *A. coustani* Laveran and *A. squamosus* Theobald constitute the anopheline fauna in the study area (Table 1).

Significantly higher numbers of both *A. gambiae* s.l. (X^2=200.5, df=1, p<0.05) and *A. pharoensis* (X^2=942.8, df=1, p<0.05) were found at Ejersa than at Kuma.

3.2 Larval density and habitat preference in the two villages

At Ejersa, of the total 1645 3rd and 4th instar larvae, 74% (1218) were collected in shoreline puddles comprising 17.4% (212) *A. gambiae* s.l., 76% (926) *A. pharoensis*, 4.4% (53) *A. coustani* and 2.2% (27) *A. Squamosu.* At Ejersa, shoreline puddles were the main habitat for the breeding of *A. pharoensis.* At Kuma, the most common breeding habitat was seasonal rain pools and agricultural puddles (Table 1).

3.3 Density of *Anopheles* larvae at different sampling periods

At Ejersa, the peak larval density of *A. pharoensis* was recorded in mid October (50 larvae/100 dips). At Kuma, the highest larval density of *A. gambiae* s.l. was also recorded in mid October (33.5 larvae/100 dips) (Figs. 4 and 5).

3.4 Turbidity, depth, vegetation, intensity of shade and larval density

The combined data on mean larval density from Ejersa and Kuma showed that *A. gambiae* s.l. was greater in slightly turbid and shallow aquatic habitats than in turbid and deep aquatic habitats ($F=16.97$, $p<0.05$ and $F=6.03$, $p<0.05$). In contrast, the density of *A. gambiae* s.l. larvae was greater in habitats with emergent aquatic vegetation and relatively open sunlit conditions ($F=11.14$, $p<0.05$ and $F=10.77$, $p<0.05$) (Table 2).

The mean larval density of *A. pharoensis* in turbid aquatic habitats was found to be significantly higher from that of slightly turbid aquatic habitats ($F=13.82$, $p<0.05$). The density of *A. pharoensis* in aquatic habitats with floating vegetation and with relatively shady conditions was significantly higher than that of the aquatic habitats with more light and more emergent vegetation ($F=15.75$, $p<0.05$ and $F=10.56$, $p<0.05$). Depth of larval habitats had no significant effect on the mean larval density of *A. pharoensis* in the study area ($F=0.84$, $p>0.05$) (Table 2).

3.5 Larval breeding water temperature, water level and larval density

In this study, the water temperature recorded throughout the study period ranged between 18 °C and 27.2 °C for breeding habitats at Ejersa, and between 22.5 °C and 25.5 °C for those at Kuma (Table 3). The water temperature of the larval breeding sites

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was entirely dependent on the variation in the atmospheric temperature. The reservoir water level increased at the start of the sampling period with the highest water level recorded (110.6 m a.s.l.) in mid September. Subsequently it fell reaching 108.8 m a.s.l. at the end of sampling period. At Ejersa, the number of positive breeding sites dropped to zero by mid-December even though the number of potential breeding sites (i.e. shoreline puddles) was actually increasing from mid-November (Fig. 6).

Weekly changes in water level of the Koka reservoir had a positive correlation with the number of positive larval habitats ($r=0.605$, $p<0.05$). No correlation existed between weekly change in water level (m) and the number of potential breeding habitats observed ($r=0.423$, $p>0.05$). Absolute water level (m) of the Koka reservoir indicated no correlation with the number of neither positive breeding habitats nor potential breeding habitats ($r=0.402$, $p>0.05$ and $r=0.473$, $p>0.05$).

3.6 Meteorological variables and larval breeding activity of *Anopheles* mosquitoes

At Ejersa, the minimum atmospheric temperature was found to be slightly positively correlated with the densities of both *A. gambiae* s.l. and *A. pharoensis* ($r=0.541$ and 0.509, $p<0.05$) (Table 4). At Kuma only rainfall showed a positive correlation with mean larval density of *A. pharoensis* ($r=0.575$, $p<0.05$), while no correlation existed between the remaining meteorological variables and mean larval density of *A. gambiae* s.l. and *A. pharoensis* (Table 4).

4 Discussion

The morphological identification of matured larvae in this study revealed four species in the vicinity of the Koka reservoir, namely *A. pharoensis*, *A. gambiae* s.l., *A. coustani* and *A. squamosus*. The occurrence of these species in the two study villages indicates dominance by two major vectors of malaria, *A. pharoensis* (61.1%) and *A. gambiae* s.l.

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(33.6%). A similar study on the vicinity of the Koka dam indicated that *A. pharoensis, A. arabiensis A. coustani* and *A. funestus* occurred in the area (Kibret et al., 2009).

The occurrence of *A. pharoensis* larvae collected at Ejersa was significantly greater than at the comparison non-reservoir site, Kuma (X^2=42.8, df=1, p<0.05). The major reason for this was that the reservoir site provides shoreline puddles that are suitable for the breeding of this species. Previous studies have shown that *Anopheles gambiae* s.l. prefers open, shallow and temporary breeding habitat (Coeteez et al., 2002) while *A. pharoensis* flourishes in shaded, permanent water bodies with large vegetated swamps, where the main larval habitat is characterized by floating plants (Gillies and De Mellion, 1968; Carrara et al., 1990).

The number of positive sites encountered throughout the sampling period was 97 for the reservoir village and 22 for the non-reservoir village. At Ejersa 66 (i.e. 68%) of the breeding habitat was shoreline puddles, whilst rain pools dominate (i.e. 83.3%) at Kuma. Shoreline puddles are turbid by nature and have lots of aquatic vegetation floating in them. Such habitat may exist for a considerable period of time because they are created in areas where the ground water level is close to surface and this increases the longevity of the puddles (Fillinger et al., 2004). The size of such puddles is much greater and typically they are deeper than the rain pools and agricultural puddles (Keiser et al., 2005). This result is consistent with that of Yohannes et al. (2005), in which in a reservoir village a total of 61 positive pools were observed while the control village was restricted to rain pools in the wet season. Kibret et al. (2009) also indicated that villages associated with the Koka reservoir were characterized by significant numbers of shoreline puddles whilst control villages were characterized by fewer and less extensive breeding sites, created mainly by rainfall.

Generally mean larval density of *A. gambiae* s.l. was greater in slightly turbid and shallow aquatic habitats than in turbid and deep aquatic habitats. Similarly larval density of *A. gambiae* s.l. was greater in habitats with emergent aquatic vegetation and with relatively open sunlit condition. Many of the rain pools and agricultural puddles were characterized by slightly turbid conditions with muddy substrate. These breeding

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sites were ephemeral and tended to dry in a relatively short period of time. This result is consistent with past observations that *A. gambiae* s.l. prefers breeding habitat with relatively less shade, muddy substrate and slight turbidity (Minakawa et al., 1999). The soil substrates provide nutrients for the enrichment of bacteria that serve as food source for larvae, and possibly as oviposition attractants.

The mean larval density of *A. pharoensis* in turbid aquatic habitats was 32.37. This was found to be significantly different from that of the slightly turbid aquatic habitats. The major reason for this was that *A. pharoensis* prefers turbid aquatic breeding habitat (Gillies and De Mellion, 1968; Carrara et al., 1990). The density of *A. pharoensis* in aquatic habitat with floating vegetation and with relatively shady conditions was found to be higher than that of aquatic habitat with more light and greater emergent vegetation. The depth of puddles made no difference to the mean larval density of *A. pharoensis* ($F=0.84$, $p>0.05$).

These results confirm that the colonization of habitat by specific types of local *Anopheles* larvae is to a large extent governed by the physical characteristics of that habitat. Similar studies conducted in Eritrea indicated that turbidity, depth of puddle and water current were the physical parameters that made a significant difference in mean larval abundance in the area (Shililu et al., 2003). These physical characteristics were also reported to bring about a significant variation in mean larval density in different aquatic habitats (Jacob et al., 2005).

In this study minimum atmospheric temperature was found to be positively correlated with mean larval density of *A. pharoensis* and *A. gambiae* s.l. at Ejersa but not Kuma. Water temperature was found to be strongly positively correlated with mean larval density of the two dominant species, *A. pharoensis* and *A. gambiae* s.l. at Ejersa. According to Shililu et al. (2003), water temperature was positively correlated to larval density in Eritrea ($r=0.167$, $p<0.01$). Studies conducted on the water temperature preference indicate that *A. gambiae* s.l. is tolerant to relatively high water temperatures (McCrae, 1983; Minakawa et al., 1999).

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In open sunlit rain pools water temperature sometimes reach 40 °C. The larvae of *A. gambiae* s.l. have the capacity to survive and may even develop more rapidly as the water temperature increases. This might be because higher temperatures encourage better development of eggs or warmer water temperatures allow the development of more microorganisms that are used as food by the larvae (McCrae, 1983; Minakawa et al., 1999).

By the end of the study period all the breeding sites at Kuma were dry and at Ejersa only relatively new shoreline puddles remained. For this reason almost all the breeding sites visited were negative for anopheline larvae. The sharp decrease in the atmospheric temperature of the area, in association with windy conditions, which may prevent adult mosquitoes from reaching the shoreline puddles to lay eggs, possibly explain the absence of anopheline larvae in the remaining breeding sites.

Another study conducted at Koka has indicated that the abundance of *Anopheles* larvae along the reservoir shoreline is affected by water level changes, with faster rates of reservoir recession resulting in reduced abundance (Kibret el al., 2009). In the current study, a similar finding was made: weekly water level changes were found to be positively correlated with the number of positive breeding habitats. Thus as the rate of change in water levels declined the amount of positive breeding habitat also decreased. This was despite the fact that, though not statistically significant, the amount of potential breeding habitat increased as water levels dropped. This confirms that the presence of suitable breeding habitat is not the only factor determining the presence of larvae. Climatic and other environmental variables also play a major role in determining the abundance of anopheline larvae.

5 Conclusions

Four *Anopheles* species were identified in the area during the study period: *A. pharoensis*, *A. gambiae* s.l. *A. coustani* and *A. squamosus*. The occurrence of *A. pharoensis* was greater in the reservoir village than in the non-reservoir village mainly because of the availability of shoreline puddles suitable for breeding. The occurrence of *A. gambiae* s.l. was also greater than that of the non-reservoir village in which the effect of the dam was not observable.

Three major *Anopheles* mosquitoes breeding habitats were identified: shoreline puddles, rain pools and agricultural puddles. Shoreline puddles were the major type of breeding habitat in the reservoir village.

The occurrence of *A. pharoensis* was greater in turbid aquatic habitat with floating vegetation. These were the principal characteristics of the shoreline puddles. *Anopheles gambiae* s.l. occurred in shallow slightly turbid habitat with emergent vegetation and open sunlit conditions. Reservoir water level changes were the major reason for the creation of potential breeding habitat (i.e. shoreline puddles) in the reservoir village. However, both water and atmospheric temperature fluctuations are important sources of differences in larval density over time.

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Table 1. *Anopheles* larval count in different types of breeding habitats in the two study sites during the study period (August–December 2007).

Village	Type of breeding site	No. positive	Number of *Anopheles* larvae collected* *A. gambiae* s.l.	*A. pharoensis*	*A. coustani*	*A. squamosus*	Total
Ejersa	Shoreline puddles	66	212 (17.4)	926 (76.0)	53 (4.4)	27 (2.2)	1218
	Rain pools	23	208 (67.3)	90 (29.1)	2 (0.6)	9 (2.9)	326
	Agricultural puddles	8	56 (47.5)	59 (50.0)	1 (1.0)	2 (2.0)	101
	Total	97	476 (28.9)	1075 (65.3)	56 (3.4)	38 (2.3)	1645
Kuma	Shoreline puddles	0	NA	NA	NA	NA	NA
	Rain pools	16	95 (83.3)	17 (14.9)	2 (1.8)	0 (0)	114
	Agricultural puddles	6	33 (86.8)	5 (13.2)	0 (0)	0 (0)	38
	Total	22	128 (84.2)	22 (14.5)	2 (0)	0 (0)	152

* Values in parenthesis are percentages of total larvae collected at each type of breeding habitat. NA=not available

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Table 2. Physical habitat characteristics and mean larval density (no. of larvae per 100 dips) of *A. gambiae* s.l. and *A. pharoensis*.

Species	Habitat characteristics		Number of larvae per 100 dips Mean±SE	F	P
A. gambiae s.l.	Turbidity	Turbid	5.55±0.25	16.97	0**
		Slightly turbid	20.13±0.46		
	Depth†	Deep	8.55±0.5		
		Shallow	15.54±0.47	6.03	0.02*
	Vegetation	Emergent	23.31±0.67	11.14	0.001**
		Floating	6.93±0.41		
	Intensity of shade	Light	19.64±0.46	10.77	0.001**
		Shade	6.09±0.29		
A. pharoensis	Turbidity	Turbid	32.37±1.11	13.82	0**
		Slightly turbid	12.2±0.85		
	Depth†	Deep	21.34±1.46	0.84	0.363
		Shallow	24.03±0.96		
	Vegetation	Emergent	10.08±0.88	15.75	0**
		Floating	31.11±1.01		
	Intensity of shade	Light	12.86±0.9	10.56	0.002**
		Shade	31.56±1.11		

* significant at $p<0.05$, ** Significant at $p<0.01$
† Aquatic habitats <0.25 cm in depth are categorized as shallow and those >0.25 cm in depth are categorized as deep.

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Table 3. Mean water temperatures and larval density of *A. gambiae* s.l. and *A. pharoensis* in different sampling interval during the study period (August–December 2007).

Sampling weeks	Ejersa Mean larval density per 100 dips			Kuma Mean larval density per 100 dips		
	Water T^0	*A. gambiae* s.l.	*A. pharoensis*	Water T^0	*A. gambiae* s.l.	*A. pharoensis*
1	20.22	7.4±1.0	27.37±3.7	(–)	(–)	(–)
2	24.44	9.5±1.1	22.54±3.0	(–)	(–)	(–)
3	25.11	13.2±1.3	39.5±4.7	(–)	(–)	(–)
4	23.11	5.9±0.9	41.5±2.8	(–)	(–)	(–)
5	23.8	14.8±1.8	25.8±2.7	22.5	7.7±0.2	2.4±0.4
6	25.73	20.7±1.2	19.70±2.5	23.4	18.0±0.8	1.30±0.2
7	21	19.8±1.4	14.6±2.1	25.5	17.2±1.2	4.0±0.6
8	23	14.5±0.7	27.1±1.6	23.6	33.4±2.7	5.1±0.9
9	26.33	1.7±0.2	50.0±1.3	24.3	25.0±1.4	6.3±0.5
10	27.2	15.6±0.6	16.9±0.8	(–)	(–)	(–)
11	26.2	4.4±0.8	33.8±0.9	(–)	(–)	(–)
12	18.2	7.9±0.2	29.8±0.7	(–)	(–)	(–)
13	18	(–)	15.63±0.8	(–)	(–)	(–)
14	18	(–)	9.3±0.5	(–)	(–)	(–)
15	(–)	(–)	(–)	(–)	(–)	(–)
16	(–)	(–)	(–)	(–)	(–)	(–)

(–) indicates no temperature reading since there was no positive breeding habitats.

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Table 4. Correlation between abundance of *A. gambiae* s.l. and *A. pharoensis* with daily mean atmospheric temperature (°C), atmospheric minimum and maximum temperature (°C) and total rainfall (mm) at Ejersa and Kuma.

		A. gambiae		*A. pharoensis*	
		r value	*p* value	*r* value	*p* value
Ejersa	Dailey mean temperature	0.451	0.079	0.451	0.079
	Min. atm. temperature	0.541	0.030*	0.509	0.044*
	Max. atm. temperature	−0.034	0.902	0.145	0.592
	Total rainfall	0.316	0.234	0.316	0.234
Kuma	Dailey mean temperature	0.140	0.604	0.056	0.838
	Min. atm. temperature	0.175	0.516	0.187	0.488
	Max. atm. temperature	−0.021	0.939	−0.189	0.483
	Total rainfall	0.575	0.020*	0.390	0.135

* Significant at $p<0.05$

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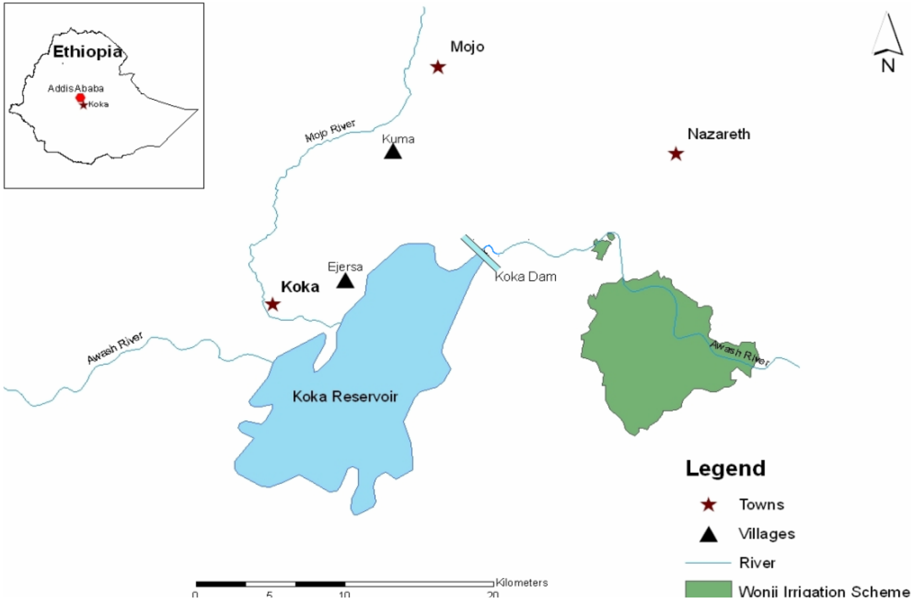

Fig. 1. Map of the Koka area in the middle course of the Ethiopian Rift Valley (triangles show the study villages) (courtesy: International Water Management Institute (IWMI), Addis Ababa, Ethiopia).

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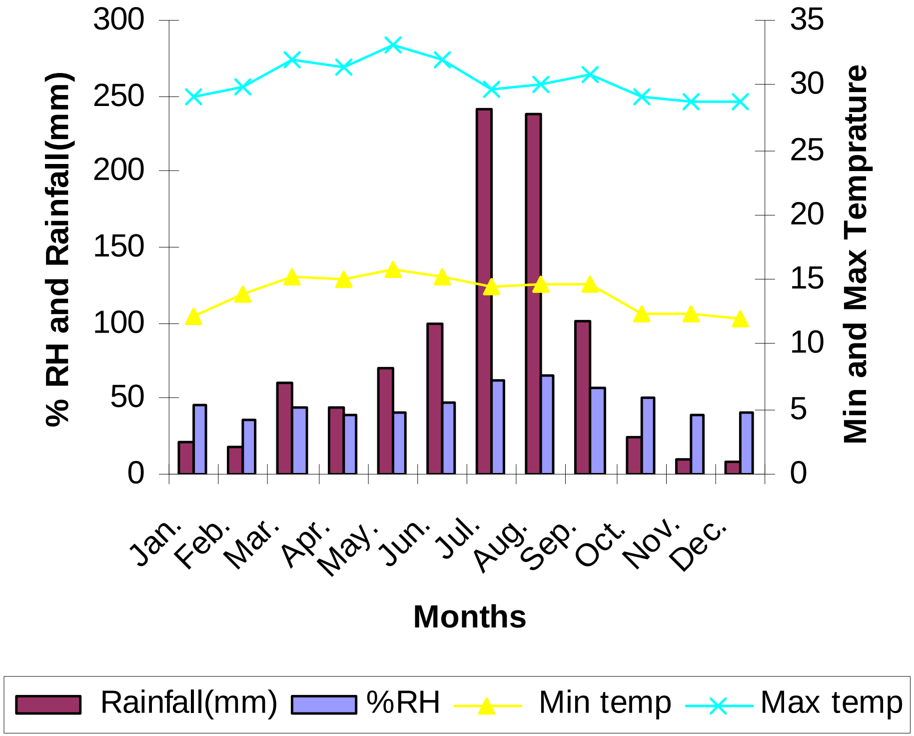

Fig. 2. Monthly mean maximum and minimum temperature (°C), relative humidity and rainfall (mm) of the Koka Dam (1998–2007) (courtesy: National Meteorological Agency, Addis Ababa, Ethiopia).

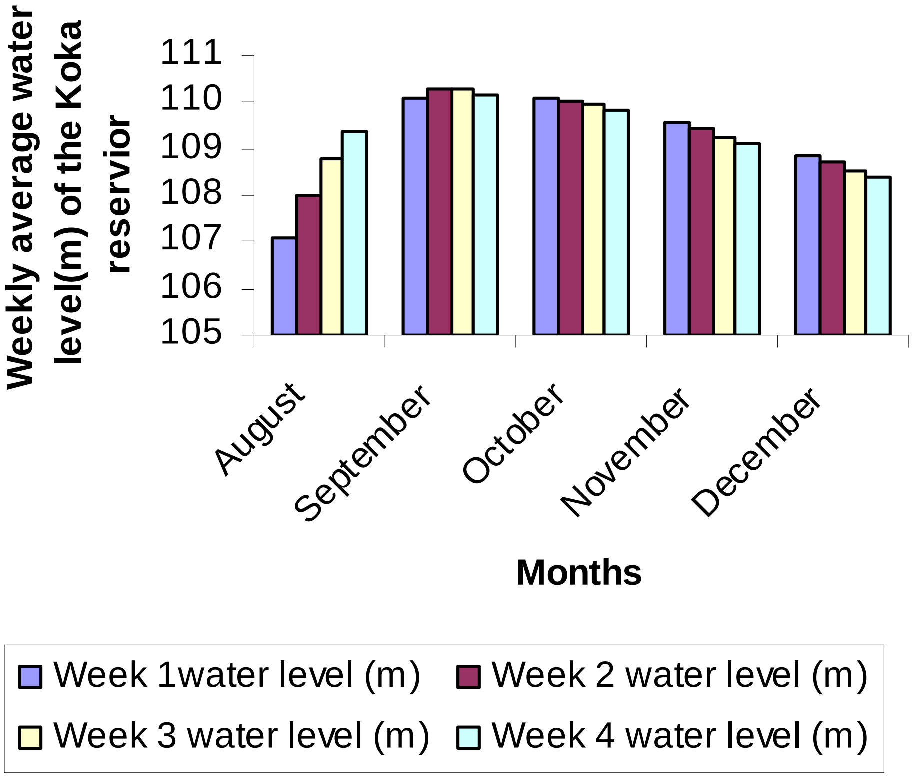

Fig. 3. Weekly mean water level of the Koka Dam for the months August–December 2007 (courtesy: Ethiopian Electric Power Corporation (EEPCo), Addis Ababa, Ethiopia).

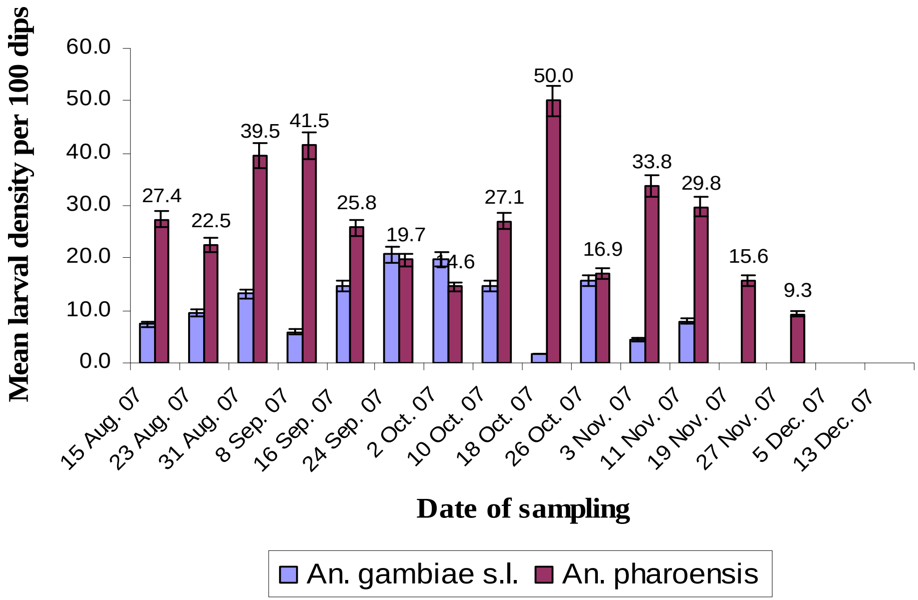

Fig. 4. Mean number of larval density (number of larvae/100 dips) of *A. gambiae* s.l. and *A. pharoensis* for the village of Ejersa (n=16 surveys).

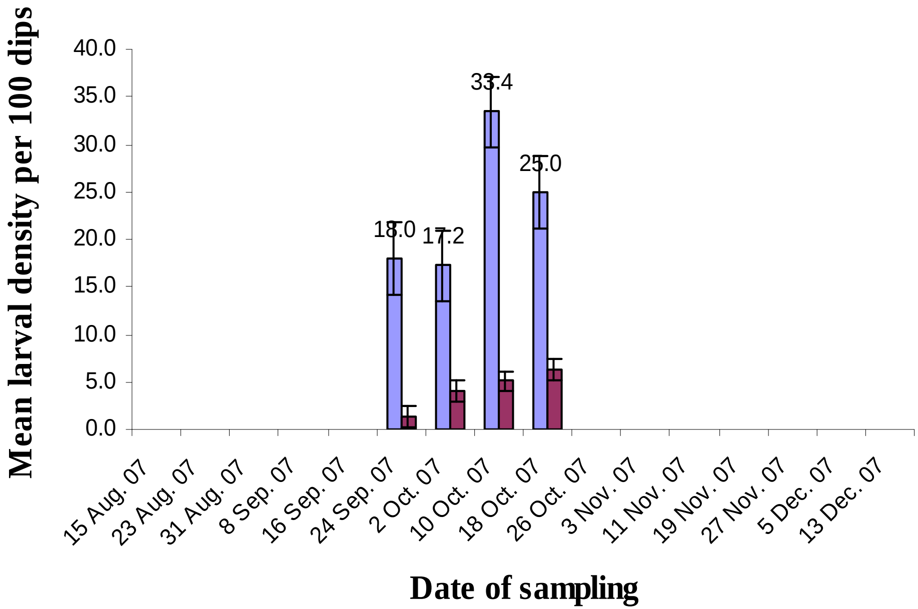

Fig. 5. Mean number of larval density (number of larvae/100 dips) of *A. gambiae* s.l. and *A. pharoensis* for the village of Kuma (n=16 surveys).

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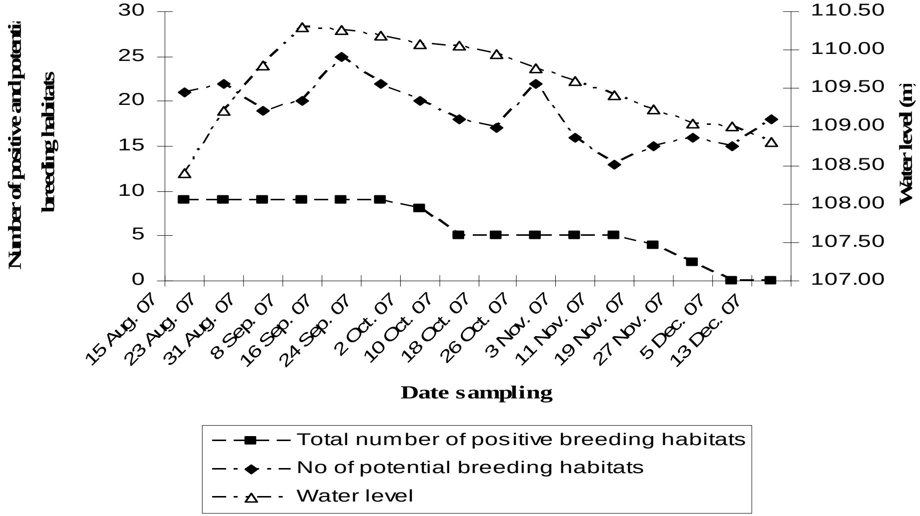

Fig. 6. Water level (m) of the Koka reservoir, number of positive breeding sites, and number of potential breeding sites (August–December 2007).

Plate 1. Fishermen in Ejersa on the seasonal lake created by the rise in water level of the Koka dam during the rainy season.

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Plate 2. Farmers cultivating following the recessing shoreline for growing vegetables.

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Plate 3. Turbid shoreline puddle with floating aquatic vegetation: an ideal breeding site for *A. pharoensis* in Ejersa, a village around the Koka reservoir.

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Plate 4. Agricultural puddle formed during the rainy season: ideal breeding site at Kuma village, located 5 km away from the shoreline of the Koka dam.

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Plate 5. Larval sampling done by the standard 350 ml dipper.

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Plate 6. Water temperature measured using a water sampling thermometer.

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